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SOME NEW RECTIFYING EFFECTS IN CONDUCTING GASES.

By P. G. Nutting.

THE passage of electricity from a metal to a gas or from a gas to a metal occurs in a manner not yet well understood. The present investigation was undertaken to determine what conditions of the metal or gas favor the transfer of electricity from one to the other and if possible to throw some light on the mechanism of surface condition. While the results here presented are crude, they bear directly on the theory of metal-gas conduction and the method, though very simple, is believed to be new. The work suggested itself during some spectroscopic work with Plücker tubes.

If we use a direct current in studying the electrode drop in potential, we are confronted by the great difficulty in keeping the condition of the surface, temperature, pressure, etc., constant and in reproducing these conditions in successive tests. But if we use an alternating current of a maximum voltage just a little above the maximum total drop in potential between electrodes, conditions cannot appreciably change between successive alternations and the excess of current in one direction may be taken as a rough measure of the relative surface conductivity at the two electrodes. It is hardly conceivable that there can be any rectifying effect due to the gas itself away from the electrodes, for this would require not only molecular or atomic dissymmetry but a fixed orientation of these particles. Hence we must regard rectification as due to conditions existing at the metal-gas surface and in the immediately adjacent

metal and gas. The general form assumed by a single phase alternating current wave when a conducting gas is included in the circuit is discussed later on in relation to the dissymmetry of the wave caused by partial rectification.

The greater part of the work here described was done with the current from a transformer of 100/2,000 volts and 600 watts capacity. Occasionally some of the work was repeated on smaller 100/1,000 volt transformers of 100 or 300 watts capacity. To control the current in the secondary, a variable non-inductive resistance of about 100 ohms was placed in the primary of the transformer. The current in the secondary varied from ten to forty milliamperes according to the density of the conducting gas. Most of the work was done with ordinary Plücker tubes slighly attered according to the conditions desired. They were of the short stout form now preferred and had either rod or disk aluminum electrodes. The tubes were connected with rubber pressure tubing to a Geryk pump and hydrogen generator by a three way cock so that they could be quickly exhausted and filled or washed with hydrogen. A direct current Weston milliammeter in series with the tube gave the amount of current rectified while an alternate current voltmeter also in series gave the total current. In this way rectification as small as half of one per cent. could be easily measured and a tenth as much detected. It is difficult to prepare a tube that will not show as much as one per cent. rectification. The effects here recorded are as large as five to forty per cent. and decidedly reversible.

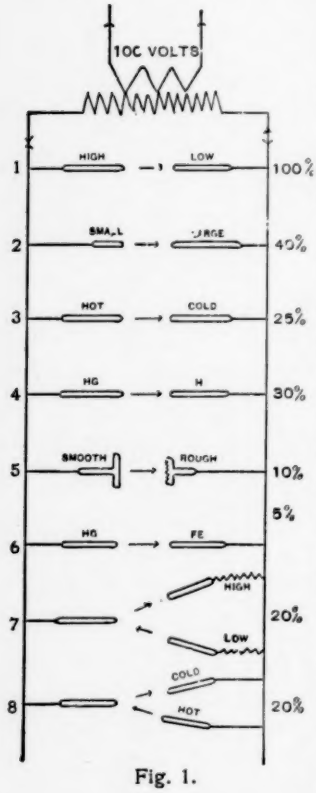


Fig. 1.

The principal rectifying effects obtained are indicated diagrammatically in the accompanying figures. The number at the left

corresponds with the number of the descriptive paragraph in the context. The titles *pressure*, *temperature*, etc., indicate the differences which cause rectification, the percentages at the right indicate the maximum percentage of the current rectified, while the intermediate arrow indicates its direction. Except the first, the effects showed but little variation in percentage of rectification with the density of the conducting gas as the pressure on this was varied from 6 to 0.1 mm.

1. The difference in pressure of the gas about the two electrodes was produced by constricting the tube to a fine capillary between the electrodes and rapidly exhausting. If the exhaustion is sufficiently rapid, complete rectification occurs, *i. e.*, half of the current wave fails to pass at all. Judging by the width of the cathode dark space the corresponding pressures in the two bulbs are about 4 mm. and 0.3 mm. Sudden admission of gas into an exhausted tube reverses the rectification.

We can hardly attribute this effect to any differences within the electrodes or to the ease of escape from metal to gas. But if we consider the current carried by the negative electrons alone, then the current will be able to start much more easily from the electrode surrounded by the more rarefied gas, for here the electrons will have a greater free path and will be more easily able to attain ionizing velocity. Hence the (negative) current will travel most easily from low to high pressure, as observed. A cruder and less tenable explanation is possible if we consider the current carried by both positive and negative electrons. The strong current of gas through the capillary from high to low pressure, would tend to sweep the larger positive electrons with it rather than the much smaller negative electrons. Hence the (positive) current would flow from high to lower pressure as observed.

2. The relative size of the electrodes is an important factor in producing rectification. The excess of current flows from the small to the large electrode. When the large electrode was three times the area of the smaller a rectification of 12 per cent. was observed; when it was ten times the area, 35 per cent. was observed. The tests were made with aluminum electrodes in Plücker tubes. When the pressure is so great and the current so small that the

glow covers only a portion of the larger electrode, the effect is null or reversed. After the current has been passing for some time, the heating effect next described (3) may mask the effect of relative size. There appears to be little if any difference in size of the cathode dark space at the large and small electrodes.

The current density being less at the larger electrode, any competition between the electrons carrying the current will be less at this electrode. At the larger electrode, negative electrons starting out would be less interfered with by the pressure of positive electrons. The effect can hardly be traced to the difference in capacity of the large and small electrodes, for connecting one electrode to a large capacity or even to earth produces but a slight rectifying effect.

3. A difference in temperature of the electrodes gives a partly rectified current from the hot to the cold electrode. When one bulb of a Plücker tube was heated to about 250° and the other bulb kept cold by a wet cloth and protected by an asbestos screen, a rectification as large as 25 per cent. was observed on starting the current. This decreased rapidly as the current heated the cold electrode. Using tubes with disk electrodes the cathode dark space was at least 50 per cent. larger at the hot electrode than at the cold. At the same time the canal ray glow within the dark space was scarely perceptible while at the cold electrode it nearly filled the cathode dark space.

A continuous current heats the cathode much more energetically than the anode. Hence when an alternating current passes between a hot and a cold electrode we should expect the rectified portion to pass in such a direction as to heat the cold electrode more than the hot and so produce equilibrium. This is what actually occurs. But the electron theory would lead up to expect a current from cold to hot. At the hot electrode negative electrons escape from the metal most easily, they have a longer free path to get started and produce ionization and this movement is less obstructed by the presence of positive electrons. Hence we should expect a negative current from hot to cold, the reverse of that observed.

4. When one bulb of a Plücker tube is filled with mercury vapor and the other with air or hydrogen, there is a decided rectifying

effect from the mercury vapor toward the hydrogen. In spectroscopic work I have frequently observed complete rectification under similar conditions.

In some previous work[1] on the spectra of mixed gases it was shown that in a mixture, other things being equal, gases or vapors of great atomic weight appear to give always greater spectral energy than those of lower. If we take this to mean that they carry current more readily or are more readily ionized, we have a simple explanation for the above rectifying effect. The current is more easily started in the bulb containing heavier vapor so that half the alternating current wave is reduced in area according to the diagram discussed later.

5. The condition of the surface of the electrodes appears to determine a slight but decided rectifying effect. Aluminum disk electrodes were used, one polished and the other cut in ridges like a file with a sharp knife. An excess of current passed from the smooth to the rough electrode. Whether this effect was anything more than that due to a greater exposed surface could not be determined.

6. With one electrode mercury and the other iron of the same size only a slight rectifying effect from mercury to iron was observed on starting the current. After the current had been running some time, mercury vapor over the mercury electrode tended by (4) to increase the rectification, while the much hotter iron electrode by (3) tended to decrease it. It would appear that the action of the Cooper Hewitt rectifier on a three phase circuit is largely due to the much greater surface exposed by the mercury electrode and the greater density of mercury vapor in its immediate neighborhood. If cathode drop of potential played an important rôle we should have obtained greater rectification with the tube just described and a single phase current.

Tests 7 and 8 were made with tubes provided with three mercury electrodes. One of these was connected to one 2,000-volt terminal and the other two through different resistances to the other. Current was found to enter through the low resistance and leave by the high. Such an effect by (3) would be produced if the low resist-

[1] Nutting, Astrophysical Journal, 19, 105–111, March, 1904.

ance electrode becoming more heated by the greater current. When connections were made with equal resistances and one electrode heated, the current passed from hot to cold in accordance with (3) and (4).

We may get a better idea of what actually occurs in the process of partial rectification from the accompanying figure (Fig. 2). Let the curve $\varepsilon(i)$ be the characteristic gas conduction curve for the

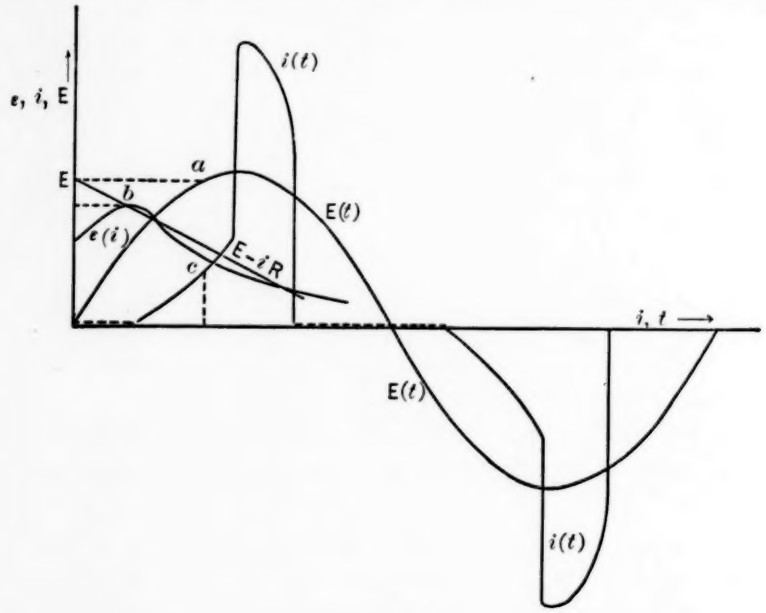


Fig. 2.

tube used, *i. e.*, the fall of potential between electrodes as a function of the current. Impress the alternating voltage $E(t)$ on the tube having such an external (ohmic) resistance in circuit that the line $E-iR$ will have the slope indicated, then $i(t)$ will represent the form of the corresponding curve of current through the tube. Any one who has ever plotted these current curves knows how entirely their form changes with even a slight change in the form of the gas curve $\varepsilon(i)$, and these $\varepsilon(i)$ curves change in form greatly as conditions in the tube are varied. For instance, at very low pressures the curves are elevated and flattened. At high pressures it may rise continually, particularly if the electrodes be small or pointed.

If the tube be illuminated by X-rays the maximum of the $\varepsilon(i)$ curve will be sharpened, lowered and displaced towards the left. If then the electrodes are under different conditions, the $\varepsilon(i)$ curve will vary in form with the direction of the current through the tube, and therefore the current curves $i(t)$ will no longer be symmetrical about the horizontal axis. The reversed (lower) part of the curve will be more flattened or rounded say than the upper and the effect will be shown as partial rectification.

A tube having one internal and one exterdal electrode showed no trace of rectification. This might have been expected since in this case the $\varepsilon(i)$ curve rises steeply and continuously and the current curve $i(t)$ is a low broad sine curve which would show little if any dissymmetry.

NATIONAL BUREAU OF STANDARDS,
April, 1904.

THE ABSORPTION OF ENERGY IN CONDENSERS.

BY R. F. EARHART.

LORD RAYLEIGH has described a method for making certain measurements in alternate current phenomena which is particularly suitable for measuring energy losses in circuits having low power-factors.[1] This instrument has been frequently referred to as Rayleigh's phasemeter. Its application to measurements of losses due to magnetic hysteresis has been successfully employed by Johonnott[2] and others.

It occurred to the writer that this method might be employed in the measurement of losses due to the absorption of energy in dielectrics. There is no doubt that it affords an accurate and simple method for determinations of this general class.

In the experiments to be described some results were obtained which may appear satisfactory. In other cases, while consistent results were obtained, the exact quantitative results are of somewhat doubtful value.

In a condenser of comparatively small capacity, say one microfarad or less, the amount of energy that will be transmitted when a perodic E.M.F. of 100 volts is applied will be small; this will apply particularly when resonance conditions are lacking. If the condenser is a good one, the amount of energy absorbed in such transmission will be a small per cent. of the energy entering the system. It will appear that the difficulty of measuring such a quantity exactly is inherent in the problem itself. It is hoped that the results obtained will show, that in certain cases at least, this method may be successfully applied. Under other conditions the possibilities for error are sufficiently great to cast serious doubts on the value of the quantitative results.

The problem will be discussed under three general heads: First, an outline of the general theory of the phasemeter and its applica-

[1] Phil. Mag., May, 1897.
[2] PHYSICAL REVIEW, Nov., 1902.

tion to the general problem of dielectric hysteresis. Second, an expression for the determination of the efficiency of a condenser subject to a simple perodic E.M.F. Third, experimental results and conclusions.

General Theory of the Instrument.

In measurements of power in alternate current circuits, it is necessary to know three things, *viz.*, the current, E.M.F., and the angle of advance or lag of the current with respect to the E.M.F. Lord Rayleigh has suggested a simple method for determining these quantities.

A piece of soft iron wire is suspended between two coils having a common axis and lying with the center of the needle in this axis. (See Fig. 1.)

If an alternate current be passed through one of these coils the needle will be subject to a couple varying with the square of the current and with 2θ, where θ is the angle the axis of the needle makes with the common axis of the coils. This will apply for any fixed position of the coils with respect to the needle. The couple will be a maximum when $\theta = 45°$. If we consider such a needle suspended in the manner described the couple on the needle due to the magnetic field created by the current will vary simply as the square of the current. A suspended needle will give deflections proportional to the couple acting and it may be shown that for small angular deflections, the deflections will be proportional to the square of the current passing through the coil. The current passing through the coil may therefore be measured by the deflection produced and expressed in scale divisions. By calibrating the instrument for the coil in a given position these readings may be reduced to any desired units.

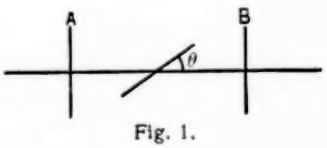


Fig. 1.

Similarly if an alternate current be passed through the second coil the current therein could be measured in a similar manner.

Again if currents be taken from points having a common P.D. and passed simultaneously through both coils, the deflections would depend on the value of the currents passing through (*A*) and (*B*) and upon their phase relation.

Consider currents of the sine type passing through (A) and (B). Let $a(\cos wt - \varphi)$ represent the instantaneous current in (A) and $b \cos wt$ the instantaneous current in (B) then

$$\frac{1}{\tau}\int_0 [Ha \cos(\omega t - \varphi)]^2 dt = \frac{H^2a^2}{2} \qquad \text{(I.)}$$

and

$$\frac{1}{\tau}\int_0^\tau [Kb \cos \omega t]^2 = \frac{K^2b^2}{2} \qquad \text{(II.)}$$

The constants H and K being such that when multiplied by the value of the instantaneous current will give the instantaneous values of the intensity of the field produced at the needles by the respective coils.

The constant $(H^2a^2)/2$ we may put $= A^2$ and will be proportional to the mean square value of the current and may be represented by the deflection of the needle.

Similarly put $(K^2b^2)/2 = B^2$.

When the currents act simultaneously through both coils giving couples we may have two cases.

First acting in the same direction

$$\frac{1}{\tau}\int_0^\tau Ha[\cos(\omega t - \varphi) + Kb \cos \omega t]^2 dt = C_1^2 \qquad \text{(III.)}$$

Second, in opposite directions

$$\frac{1}{\tau}\int_0^\tau Ha[\cos(\omega t - \varphi) - Kb \cos \omega t]^2 dt = C_2^2 \qquad \text{(IV.)}$$

Also

$$\begin{aligned} C_1^2 &= A^2 + B^2 + 2AB \cos \varphi. \\ C_2^2 &= A^2 + B^2 - 2AB \cos \varphi. \end{aligned} \qquad \text{(V.)}$$

Solving for $\cos \varphi$ we have

$$\cos \varphi = \frac{C_1^2 - C_2^2}{4AB.} \qquad \text{(VI.)}$$

By using one coil to obtain readings giving the P.D. between two points, the second coil to obtain the current flowing through any system from these same points and then using both coils simultaneously, all the data necessary for calculating energy loss in the system will be afforded.

In the application of this method to energy losses in condensers, the condenser was placed in a circuit containing one such coil; the other serving to measure the P.D. The arrangement is shown in Fig. 2. S_1 and S_2 are switches, the one is the circuit containing the condenser being a reversing switch.

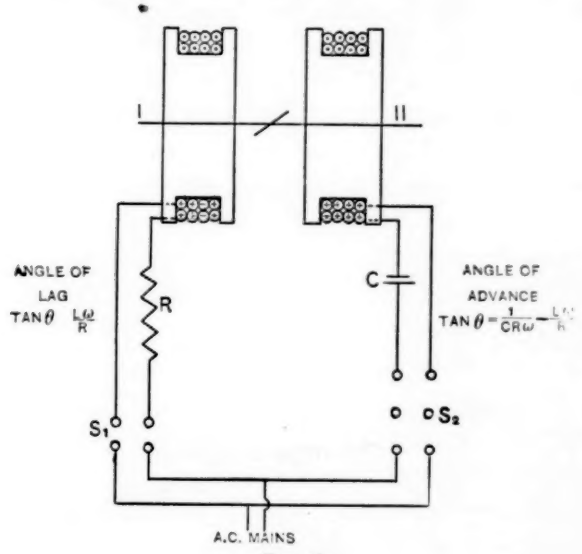


Fig. 2.

The angle of advance of the current over the E.M.F. in the condenser circuit may be calculated from the well-known formula

$$\tan\theta = \frac{1}{CR\omega} - \frac{L\omega}{R} \qquad \text{(VII.)}$$

The coil contained in the condenser circuit had an external diameter of 8.5 cm. and consisted of 24 turns of heavy copper wire. The resistance of this entire branch, obtained by short-circuiting the condenser was .67 ohms. For a condenser of 1 microfarad capacity and on a circuit having a frequency of 60 cycles we can calculate the angle of advance assuming no absorption occurs

$$1 \text{ microfarad} = 1 \times 10^{-15} \text{ C.G.S. units.}$$

$$.67 \text{ ohms} \quad .67 \times 10^{9}$$

$$\omega = 376$$

Whence from VII. $\tan \varphi = 3968$.

The second term of the right hand member (Equation VII.) can be entirely neglected since this additive term will be very small and the first term large. The angle corresponding to $\tan \theta$ is 89° 59′ 20″ or for a perfect condenser in such a circuit the current leads the impressed E.M.F. almost 90°. The departure from this angle of lead is less than one minute.

In the E.M.F. circuit a coil similar to the current coil is used. In this circuit is placed noninductive resistance amounting to about 4,000 ohms, so that in this circuit we have the condition for the current to be in phase with the E.M.F. In such a system the condenser current leads the E.M.F. by 90° provided no absorption of energy occurs. It remains then only to measure the actual advance by means of the four readings suggested previously and the angle of advance computed from formula VI. The difference between these two angles will give the angle of hysteretic lag. It is to be remembered that the phasemeter gives the cosine of the difference in phase which exists between the current and E.M.F. and for a good condenser this will not differ greatly from 90° and here the cosine changes most rapidly, hence the advantage of the method. It is desirable that the resistance of the current coil be kept as low as possible. The relation $\tan \theta = 1/CR\omega - L\omega/R$ will show that if the resistance of this coil and connections be several ohms we could not assume that the current would lead the E.M.F. by 90°. It would then be quite possible to compute what the advance would be for a perfect condenser and to obtain the actual advance, obtaining the angle of hysteretic lag in this way. This is objectionable, however, owing to the fact that the cosine of the angle changes essl rapidly and a sacrifice in sensibility would result. There is no difficulty in obtaining the first condition referred to. Using a delicate suspension with a concave mirror for determining deflections, and with a scale distance of 1 meter, deflections of something like 90 divisions were obtained for a 1 microfarad condenser and on a 110-volt circuit. This gives sufficient sensibility in this case.

Determination of the Efficiency of a Condenser Subject to a Simple Perodic Electromotive-Force.

In deducing the expression for cos φ (Equation VI.) which measures the actual advance of the current over the E.M.F., Lord Rayleigh has shown that this relation holds good for E.M.F.'s departing from the sine form. In calculating the efficiency of a condenser when the angle of advance is known, we may proceed from the following considerations, assuming the current to be of the

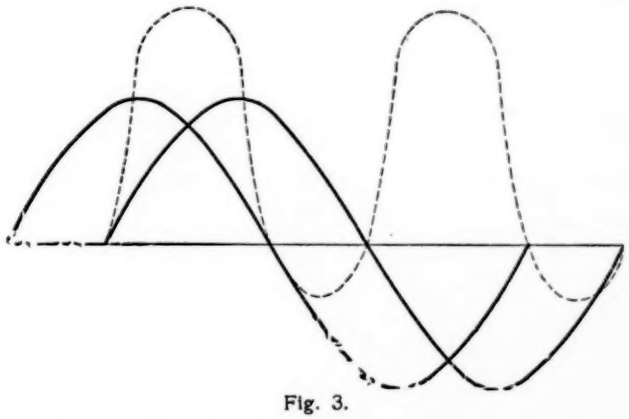


Fig. 3.

sine type. In Fig. 3 let the heavy curves represent the E.M.F. and current. The power curve will be represented by the dotted line. If we define efficiency as the ratio of the work done by the condenser in discharge, to the work done in charging it, then we can obtain the efficiency.

$$\text{Efficiency} = \frac{\text{Area of negative loop}}{\text{Area of positive loop}}.$$

It will be the ratio of the area of the negative loop to the area of the positive loop when a given phase relation exists between E.M.F. and current.

The area of the positive loop will be

$$\frac{E_1 I_1}{\omega} \cos \varphi \left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_0^{\pi-\phi} - \frac{E_1 I_1}{4\omega} \sin \varphi \left[\cos \omega t\right]_0^{\pi-\phi}.$$

For the negative loop we have the same expression between the limits $\pi - \varphi$ and π or

$$\frac{E_1 I_1}{\omega} \cos \varphi \left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_{\pi-\phi}^{\pi} - \frac{E_1 I_1}{4\omega} \sin \varphi \left[\cos \omega t\right]_{\pi-\phi}^{\pi}.$$

Where E_1 is the maximum value of the impressed E.M.F.

I_1 is the maximum value of the instantaneous current.

$\omega = 2\pi n$ where n is the frequency.

For the analytical work see Rosa on the Dissipation of Energy in Condensers, PHYSICAL REVIEW, Jan., 1899.

It is therefore possible to obtain the phase relation from the phasemeter readings and apply them in this case to the determination of efficiencies.

RESULTS.

Referring again to Fig. 2, it will be seen that circuits I. and II. proceed from points having a common difference of potential. The low resistance coils forming the phasemeter portion of the circuit were wound on wooden spools and all large masses of metal avoided in the construction, it being desirable to avoid any unknown effect due to eddy currents caused by the varying field. The soft iron needle was about .8 cm. long and was suspended by a phosphor-bronze strip. The suspended system consisted of the needle, a concave mirror and a mica vane. The resistance included in the E.M.F. circuit consisted of a series of incandescent lamps. Such resistances have practically negligable inductance and capacity. The current passing through them will be small and while the resistances will vary with temperature, after a current has been maintained through them for a short time, the resistance will not change appreciably. The time required for a complete set of readings is short and it is only necessary that the resistance should not change during that time. It is unessential just what that resistance shall be, so long as the inductance of the circuit is low.

Several condensers were used. The following measurements were made on a Leeds 10 microfarad condenser, subdivided into sections of 1 microfarad each. These condensers are guaranteed to withstand a P.D. of 1,000 volts. The dielectric consists of waxed paper concerning which the manufacturer does not speak.

The alternate current source was supplied by the mains extending to the university buildings. The fluctuations in E.M.F. in such a circuit cannot be eliminated and are the source of much trouble. In this case a second phasemeter was placed across the mains and by the indications of this "pilot" phasemeter any disturbances on

Condenser Section.	A^2	B^2	C_1^2	C_2^2	$\cos\phi = \frac{C_1^2 - C^2}{4AB}$	ϕ Angle Advance.	Efficiency.	Equivalent. Rest in ohms.
1	83	109	190.0±.2	192.8±.2	.0074	89° 35′	97.8%	18.5
2	91	108	197.0	200.2	.0080	89 32	97.5	21.3
3	117	109	224.2	227.8	.0079	89 33	97.6	19.1
4	94	108	200.4	203.4	.0075	89 35	97.8	16.4
5	92	108	199.0	202.0	.0075	89 35	97.8	16.6
6	87	108	194.2	198.0	.0115	89 21	96.5	30.3
7	88	108	194.0	197.0	.0077	89 34	97.7	20.2
8	88	107	194.0	197.4	.0087	89 30	97.3	21.0
9	102	109	209.2	212.6	.0080	89 32	97.5	19.9
10	77	109	185.2	188.0	.0076	89 34	97.7	22.4

the mains could be detected. It is necessary to take sets of readings under standard conditions and readings were taken when the pilot instrument indicated no disturbance during a set of readings. The readings given apply to a frequency of 60 cycles.

In the table of readings the headings of the columns are self-explanatory with the exception of the last one. Rowland has shown that a condenser possessing absorption behaves like a perfect condenser with a resistance in series. The last column gives this effective resistance. The readings in column (A^2) indicate that the capacities of various sections are not equal. In computing the effective resistances for the different sections, the true capacity of the section was taken. The readings given represent the mean of several readings all of which were consistent and lie within the limits of error indicated.

By using coils having different resistances and at varying distances from the needle, results were obtained which show good agreement with the recorded observations. It was necessary in this case to compute the theoretical angle of advance and determine the true angle of advance. From this data the results were computed.

A long series of measurements were undertaken which leave much to be desired. An attempt was made to study the change in absorption in a condenser when changing its capacity, without changing the amount of the dielectric possessing absorption. With this end in view, several condensers were laid up, consisting of tin-foil and paper. These condensers were placed in a letter press; so that by varying the pressure the capacity could be varied, and an attempt made to determine whether the absorption changed under these conditions. The condensers after being prepared as described were heated to a temperature of approximately 120° C. and maintained at that temperature for several hours in order to rid the paper of water vapor, so far as possible. The whole arrangement was then placed in an air-tight box and the press operated through a stuffing box, the object being to prevent any change in the dielectric. Paper to a certain extent is hygroscopic and the absorption of water from the air will alter its character. Before adopting this precaution, results of a rather erratic character were obtained. This precaution does not, of course, eliminate water but merely makes possible a constant hygrometric state. In the case of certain condensers variations in capacity of from .5 to 1.2 microfarads were obtained, but the results will hardly admit of quantitative discussion. Such condensers as I have described are practically air condensers and possess so small a coefficient of absorption that the results are of little value. The efficiency in most cases is above 99 per cent., corresponding to a power factor of .003. Unsteadiness in the line potential was sufficient to mask quantitative results. I have, however, persisted in attempting to accomplish this notwithstanding.

Ten condensers were laid up at different times and the results based on several hundred sets of readings.

In eight of the ten cases the condensers showed an increase in absorption with increase in capacity. In the other cases no change could be detected. It seems possible to explain the increase in absorption in this way.

A condenser of the type described is made up of two dielectrics: first air, possessing no absorption; second of a medium possessing some absorption. In increasing the capacity we are squeezing out

air or the nonabsorbing medium, while the absorbing medium forms a larger proportion of the combination dielectric. If my results are of any qualitative value they are certainly too small upon which to base any quantative statement.

The preliminary portion of this experiment was carried on at the Rose Polytechnic Institute of Terre Haute, Ind., the latter portion at Columbus, Ohio.

PHYSICAL LABORATORY, OHIO STATE UNIVERSITY,
COLUMBUS, OHIO, March, 1904.

STUDIES IN LUMINESCENCE.

BY EDWARD L. NICHOLS AND ERNEST MERRITT.

III. ON FLUORESCENCE SPECTRA.

IN a recent paper[1] the authors have described spectrophotometric measurements of fluorescent solutions of fluorescein, eosin and naphthalin-roth, the results of which fully confirm the contention of Lommel[2] that in the case of these substances Stokes' law is not fulfilled. In the opinion of Lommel all other fluorescent substances, with the probable exception of chlorophyll, conform to Stokes' law, the shortest wave-length of the fluorescence spectrum being always of less refrangibility than the longest wave-length capable of exciting fluorescence. We have since extended our measurements to various other fluorescent substances, determining in each case by means of the spectrophotometer the location and character of the absorption band with which fluorescence is associated and the form of the curve of relative intensities in the fluorescence spectrum.

Rhodamin and Resorcin-blau.

Of the substances examined rhodamin and resorcin-blau belong to the same group as those previously examined, being organic dye stuffs which show fluorescence in solution. The fluorescence of these solutions was of sufficient intensity to permit of the use of the method described in our previous paper which, briefly, was as follows: the light of a Nernst filament was dispersed by means of a large spectrometer with a flint prism, and that portion of the spectrum which was to be used for excitation was isolated by means of a slit mounted in place of the eyepiece in the observing telescope. Two nearly monochromatic regions of the spectrum were selected in each case, one lying well within the absorption band of the solution and the other as far toward the red as it was possible to go without reducing fluorescence to an extent which rendered measurements inexact. The fluorescence spectrum was observed by means

[1] Nichols and Merritt, PHYSICAL REVIEW, Vol. XVIII., p. 403.

[2] Lommel, Poggendorff's Annalen, vols. 143, 159 and 160.

of a Lummer-Brodhun spectrophotometer from a direction at right angles to that of the exciting ray. The solution was placed in a glass cell with plane faces, the exciting light being introduced through a slit and passing through the layer of liquid lying next to the wall of the cell through which the fluorescent light passed.

Figures 11 and 12 give in graphical form the results of these measurements. The curves of the fluorescence spectra are of the same type as those of fluorescein, eosin and naphthalin-roth given

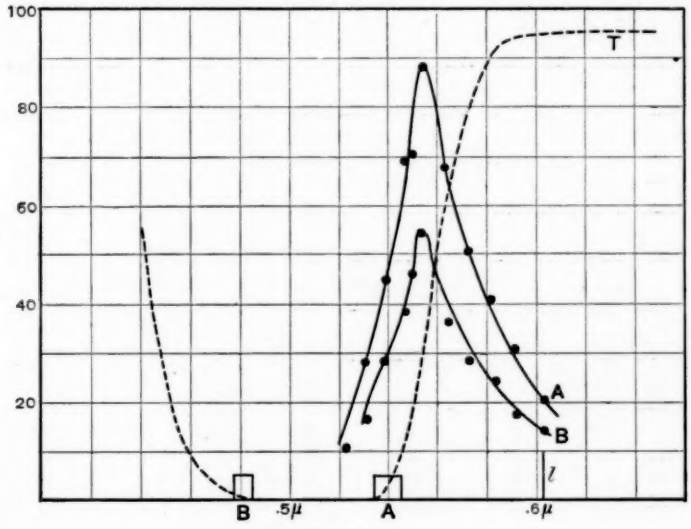


Fig. 11.

Rhodamin. Curve *A*. Fluorescence spectrum when excited by green light in the region marked *A*.

Curve *B*. Fluorescence spectrum when excited by blue light (*B*).

Curve *T*. Transmission spectrum. Layer 1.1 cm. thick.

in the paper already cited. They rise from within the region of the absorption band to a well-defined maximum, which is located, generally speaking, near the infra edge of the band; beyond the maximum they fall away rapidly with increasing wave-length. The comparison spectrum in these, as in the previous cases, was that obtained from the light diffusely reflected by a block of magnesium carbonate illuminated by an acetylene flame.

Neither of these solutions conforms even approximately with the law of Stokes. Curve A of Fig. 12 (resorcin-blau) was ob-

tained by means of light none of which was of shorter wave-length than .642 μ whereas the fluorescence is of measureable intensity to 600 μ. The rhodamin solution affords a striking example of the non-validity of the law; for although the *maximum* of the fluorescent spectrum lies at .554 μ an observable fluorescence was produced by means of a very nearly monochromatic light, obtained by the method of double dispersion, using two spectrometers in series as described in our previous paper, the shortest wave-length of which was .602 μ. This limiting wave-length is indicated by the line marked *l* in the figures. This substance, like eosin, which has its

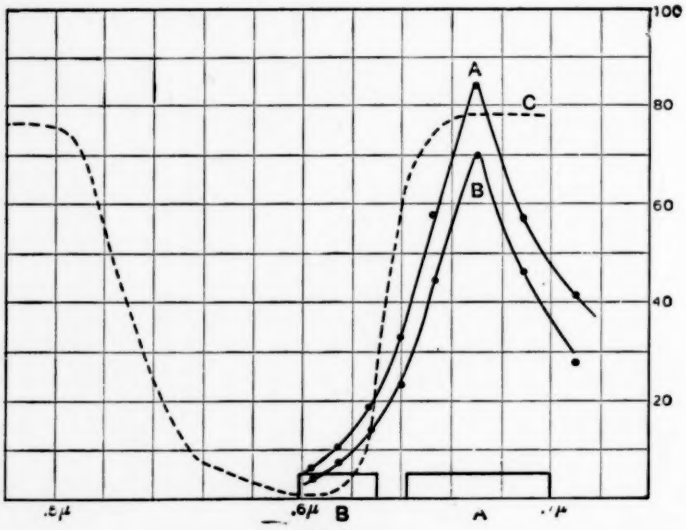


Fig. 12.

Resorcin blau in methyl alcohol. Curve *A*. Fluorescence spectrum when excited by red light lying in the region marked *A*.

Curve *B*. Fluorescence spectrum when excited by orange light (*B*).

Curve *C*. Transmission spectrum of layer 1.1 cm. thick.

maximum of fluorescence at .580 μ will respond to the excitation of light of the *D* lines of sodium or to even longer waves if of sufficient intensity.

The other substances to be considered in this paper are more difficult subjects for quantitative work because, being less strongly fluorescent, it is necessary to have recourse to powerful illumination, and because in several instances the fluorescence band lies near the limits of the visible spectrum — either in the violet or in the extreme red.

Quinine Sulphate.

The quinine sulphate subjected to measurement was prepared by making a saturated solution in water containing a trace of sulphuric acid. The solution was exposed to diffuse daylight in a cubical cell of glass, the faces of which measured 8 cm., and the fluorescence was observed through a slit in one of the faces at right angles to that exposed to the light. This slit was placed as near the corner of the cell as possible, so as to bring the layer of liquid lying next the glass on the exposed side into the field of view. The reference spectrum, as usual, was obtained from the light diffusely reflected from a block of magnesium carbonate, but in this case the surface of the block was illuminated by daylight so that the fluctuations of intensity might affect both spectra equally and in the same sense.

The transmission of the solution was determined by placing a second block of magnesium carbonate behind the cell and determining the intensity of the light transmitted by the liquid in the various regions as compared with that reflected from the first block. The instrument used in this and in many of the subsequent measurements to be described was a spectroscope, the collimator of which was furnished with a double Vierordt slit. Light for the comparison spectrum was introduced by means of a right-angled prism and the adjustment of intensities was made in the usual manner by means of micrometer screws.

A second set of measurements with this substance was made with the Lummer-Brodhun spectrophotometer. A mercury arc lamp was used in place of the Nernst filament of our previous experiments and the ultra-violet line .365 μ, isolated by dispersion with the large spectrometer, was employed for excitation. The comparison spectrum in this case was the magnesium block illuminated by means of the acetylene flame.

It is obvious that owing to the different distribution of intensities in the spectra of daylight and of the acetylene flame these two sets of observations would not be strictly comparable. In order, however, to make them at least approximately so, the following correction was applied to the observations by daylight. From certain data obtained by Vogel[1] and published by him many years ago, a curve was plotted

[1] Vogel, Berliner Monatsberichte, 1880, p. 801.

giving the distribution of intensities in the spectrum of diffuse daylight with clouded sky, the spectrum of a petroleum gas flame being taken as the standard. Vogel's measurements agree as well as could be expected, considering the fluctuating character of daylight, with those subsequently made by W. H. Pickering[1] and by Nichols and Franklin.[2] As the sky was overcast at the time of making the observations on quinine sulphate just described it was assumed that the quality of daylight would on that occasion be represented with sufficient accuracy by means of this curve. By means of a similar

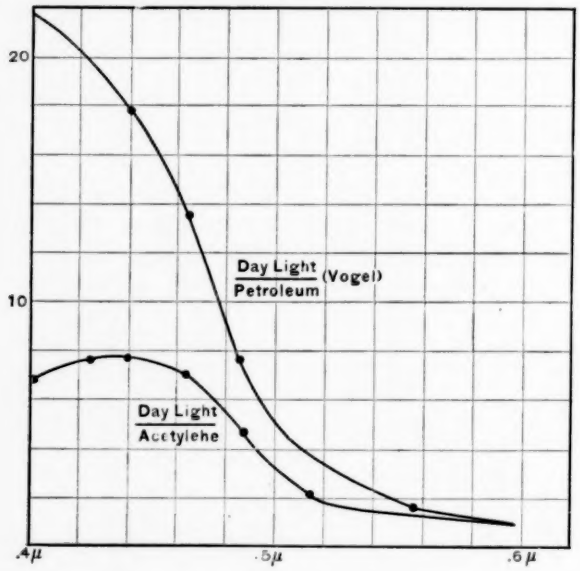


Fig. 13.

The two sources being so adjusted as to have the same intensity at the *D* line, the curve shows the ratio of intensities for other wave-lengths.

curve giving the distribution of intensities in the spectrum of the acetylene flame as compared with the petroleum flame it is possible to determine the relation between daylight and the acetylene flame. Vogel's curve for *daylight-petroleum* and the computed curve for *daylight-acetylene* are given in Fig. 13. By means of the latter it is possible, from the observations upon quinine sulphate to compute a curve in which the light of the acetylene flame reflected from mag-

[1] Pickering, W. H., Proc. Am. Acad. of Arts and Sciences, vol. 25, 1880.

[2] Nichols and Franklin, American Journal of Science, vol. 38, p. 100, 1889.

nesium carbonate is the standard. This curve (*B*, Fig. 14) corresponds precisely as regards the location of its maximum with curve *A* in the same figure, which shows the results of the measurement of the fluorescence of this substance when excited by means of the ultra-violet of the mercury lamp. Since these two sets were made with different types of spectrophotometer their agreement affords a desirable check upon the performance of the two instruments.

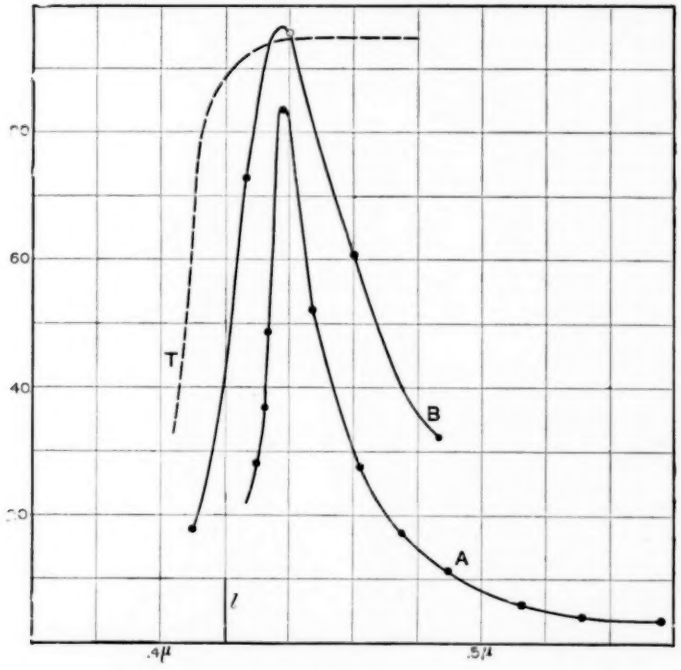


Fig. 14.

Quinine Sulphate in water. Curve *A*. Fluorescence spectrum when excited by Hg line, .3650 μ.

Curve *B*. Fluorescence spectrum when excited by daylight.

Curve *T*. Transmission spectrum. Layer 8 cm. thick.

The curve *T* gives the transmission of the solution as measured by the method already described. It was not found possible, owing to the fact that this solution remains transparent almost to the limits of the visible spectrum, to go very far into the absorption band; but the observations suffice to locate the infra edge of the band very closely. To gain further information concerning the nature

of the absorption band a series of photographs of the transmission spectrum were taken by means of a Rowland grating with sunlight as the source of illumination. The infra edge of the band as shown by the disappearance of the Fraunhofer lines was found to lie in the region indicated by the spectrometric measurements shown in Fig. 14. Absorption became almost complete in the neighborhood of the *H* lines and continued throughout the ultra-violet, at least up to the point where glass becomes opaque.

In order to determine if possible the position of the ultra edge of the band the quinine solution was placed in a cell with quartz walls and photographs were taken, using an arc light into which zinc had been introduced as a source. Lines due to this metal were distinguishable in the comparison spectrum as far as wave-length .2558μ to which point the opacity of the solution of quinine sulphate was found to be complete.

It will be seen from the curves *A* and *B* (Fig. 14) that the fluorescence spectrum of quinine sulphate is of the same type as that of the various fluorescent dye stuffs. It consists of a single band with a sharply defined maximum at .437μ. Since the curves obtained with daylight and with monochromatic light from the mercury arc are identical, as regards the position of the maximum and in general form, and since they are of the same type as the various other fluorescence spectra already described, it is evident that quinine sulphate belongs to the same class as fluorescein, eosin, etc. It is true that in the case of this substance it is possible to trace the fluorescent light throughout nearly the entire spectrum, a point which is to be considered further in a subsequent paragraph, but beyond .5μ intensities are very small.

Contrary to the view expressed by Lommel the fluorescence of quinine sulphate appears to be independent of the wave-length of the exciting light. Since, however, this is one of the substances which has been cited in support of Stokes' law, it was deemed important to determine as carefully as possible the longest wave-length of monochromatic light capable of exciting fluorescence. This is a matter of considerable difficulty on account of the weakness of the effect. By means of the method of double dispersion already described, the electric arc being used as a source, monochromatic

light thoroughly free from all stray radiation was obtained. When this was used for excitation the last trace of observable fluorescence was found to disappear at wave-length .420 μ.

In no other case have we found this limiting wave-length to lie so close to the ultra edge of the fluorescence band. It will be noted, however, that in making measurements by daylight readings were obtained at wave-length .41 μ and the fluorescence under strong excitation is traceable still further into the violet, certainly almost, if not quite, to .40 μ. While quinine sulphate then approaches more nearly to conformity with Stokes' law than the other substances that we have studied, the evidence is distinctly in favor of the view that it, like other fluorescent materials, is capable of being excited by all wave-lengths of light lying in or on the infra edge of its absorption band; and that the longest wave-length capable of producing an observable fluorescence is appreciably less refrangible than the shorter wave-lengths of its fluorescence spectrum.

Chlorophyll.

The fluorescence spectrum of chlorophyll was studied by Stokes[1] who found, in addition to the usual red band, a fainter excitation in the green of the spectrum. Hagenbach[2] subsequently made an exhaustive study of this substance. It was his opinion that it did not conform to the law of Stokes. Lommel[3] placed chlorophyll in his first class, to which belong all substances the fluorescence of which is independent of the wave-length of the exciting light.

The solution of chlorophyll used in our measurements was made by digesting green leaves in absolute alcohol and filtering. The transmission curve (Fig. 15) shows four well defined bands, of which the one to which fluorescence is due is more intense and broader than the others. Measurements made in the extreme red appeared to indicate the presence of still another region of diminished transparency which it was not possible to map with the spectrophotometer. In the hope of determining more definitely the character of this band and of ascertaining whether the series of striking absorption bands in the visible spectrum extends into the infra-red, we

[1] Stokes, Philos. Trans., 1853.
[2] Hagenbach, Poggendorff's Ann., 141, page 245.
[3] Lommel, l. c.

requested Mr. W. W. Coblentz, who is engaged in the study of the infra-red by means of a radiometer and a mirror spectrometer with rock salt prism, to explore the spectrum of this solution. The results of his measurements are plotted in Fig. 16. His observations extend from .61 μ to 1.45 μ at which wave-length the alcohol in which the chlorophyll was dissolved becomes so nearly opaque as to prevent further readings. The fluorescence band at .675 μ is clearly shown; also the band at the extreme edge of the visible red .745 μ. The latter however is of little intensity. In Mr. Coblentz's measurements comparison was made between a cell filled with the chlorophyll solution and the same cell when filled with alcohol in which no chlorophyll had been dissolved. The curve

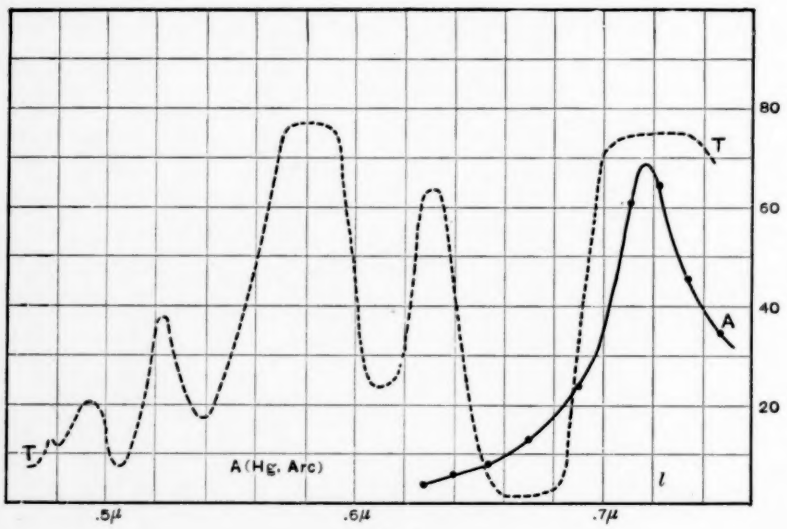


Fig. 15.

Chlorophyll (fresh alcoholic solution from green leaves). Curve *A*. Fluorescence spectrum when excited by Hg arc.

Curve *T*. Transmission spectrum of a layer 1.1 cm. thick.

therefore indicates the effect of the chlorophyll and other dissolved matters upon the transparency of the alcohol. It will be noted that between .8 μ and .9 μ the material in solution has no absorbing power. At the latter wave-length absorption again begins to show itself and increases steadily to 1.45 μ where the transmitting power of the solution is only 60 per cent. as great as that of the alcohol itself.

In determining the fluorescence curve *A* (Fig. 15) which was obtained by using the green line of the mercury arc (.546 μ) for excitation, we were able to trace the fluorescence to wave-length .624 μ, which lies well beyond the ultra side of the absorption band. This had not been found possible in the case of the fluorescence spectra previously described, partly on account of the greater width of the bands, and partly for the following reason. The fluorescence spectrum of chlorophyll is doubtless traceable to an unusual distance towards the violet because the maximum lies in the extreme red, in a region of very low luminosity. Fluorescence in this region, to be appreciable, must be of great intensity, and on the side towards the

Fig. 16.

Transmission of chlorophyll in the infra-red. (Measurements by W. W. Coblentz.)

violet the rapidly falling intensity is largely counterbalanced by increase in luminosity. The same is true of the infra side of the fluorescence band of substances like quinine sulphate; so that, although the curves are of the same type as those described in our previous paper — fluorescein, etc. — the fluorescence can be followed nearly through the spectrum. The curves of resorcin-blau, fluorite, and æsculin afford other examples of this phenomenon. Where, on the other hand, the maximum is in the middle of the spectrum, as in the case of rhodamin, eosin, fluorescein, etc., the fluorescence soon be-

comes too small for measurement on both sides of the maximum because of the diminution of luminosity toward the ends of the visible spectrum.

The green fluorescence described by Stokes was faintly discernible under strong illumination, but its intensity would not permit of measurements. This band is probably due to the presence of some slightly fluorescent substance other than chlorophyll.

The question of the applicability of Stokes' law to this solution was tested by observing with monochromatic light, by the method already described, the longest wave-length capable of producing appreciable fluorescence. The limiting wave-length (.720 μ), which gave faint but unmistakable fluorescence (see line *l*, Fig. 15), lies on the infra side of the maximum of the curve *A*.

Canary Glass.

In our experiments upon canary glass one corner of a rectangular slab 1 cm. in thickness and 7 cm. wide was used. This was mounted in front of the slit of the Lummer-Brodhun spectrophotometer in place of and in a position corresponding to the cell employed in the study of the fluorescent solutions. Fluorescence was excited in the manner already described by means of light entering the glass at right angles to the axis of the collimator tube. Measurements were made using the Hg line .407 μ (see curve *A*, Fig. 17) and green light from the spectrum of the Nernst filament (curve *B*).

To determine the location of the absorption band, light transmitted through the entire width of the glass, giving a layer 7 cm. thick, was measured. The transmission curve *C* shows a minimum, but by no means complete opacity, at .472 μ. The absorption spectrum of this specimen did not exhibit the complex character of that studied and described by Stokes in his memoir already cited. Our quantitative exploration however did not extend beyond the determination of the infra edge of the band exciting fluorescence. The fluorescence spectrum, contrary to expectation, appears to belong to the same simple type as that of the fluorescent substances previously examined. The glass was optically very imperfect and the fluorescence measurements were seriously interfered with by the presence of stray light. This shows itself in the case of curve *B*, which is

distorted in the regions corresponding in wave-length to the exciting light. The observations upon the ultra side of the curve are, as will be seen from the figure, considerably raised above the probable normal trend of the curve, which is shown by means of the dotted line. Curves *A* and *B* however have their maxima at the same wave-length, and, apart from the discrepancy just mentioned, their type corresponds precisely with that of the numerous other fluorescent spectra examined.

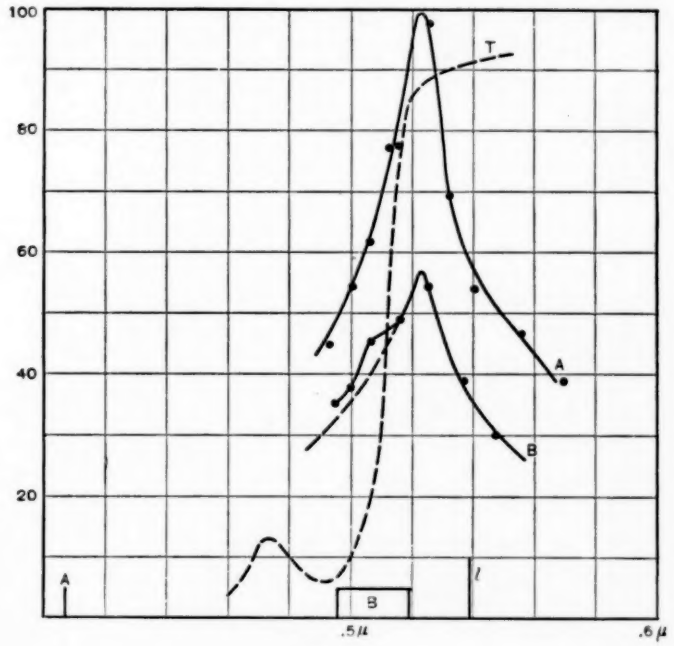


Fig. 17.

Canary Glass. Curve *A*. Fluorescence spectrum when excited by violet light, $\lambda = 0.407\ \mu$.

Curve *B*. Fluorescence spectrum when the exciting light lay in the green, in the region marked *B*.

Curve *T*. Transmission spectrum for a layer 7 cm. thick.

In the determination of the maximum wave-length capable of exciting fluorescence it was especially necessary to distinguish between fluorescent light and ordinary diffusion due to the imperfect optical properties of the glass. When one allows the spectrum to pass through this glass the path of the rays remains visible throughout the entire spectrum instead of disappearing when fluo-

rescence ceases, as is the case in an optically perfect medium. By means of a Nicol prism held before the eye it was however easy to distinguish sharply between fluorescence and ordinary diffusion. The vertical line l marks the limiting wave-length ($.539\,\mu$) at which fluorescence becomes inappreciable. It lies far to the infra side of the maximum, showing that in this, as in all previous cases, there was not even approximate conformity to the law of Stokes.

It is probable that the glass studied by Stokes, and by means of which he observed such extraordinary fluorescence phenomena, was altogether different from our specimen. It contained perhaps other fluorescent materials in solution which were absent in the glass now

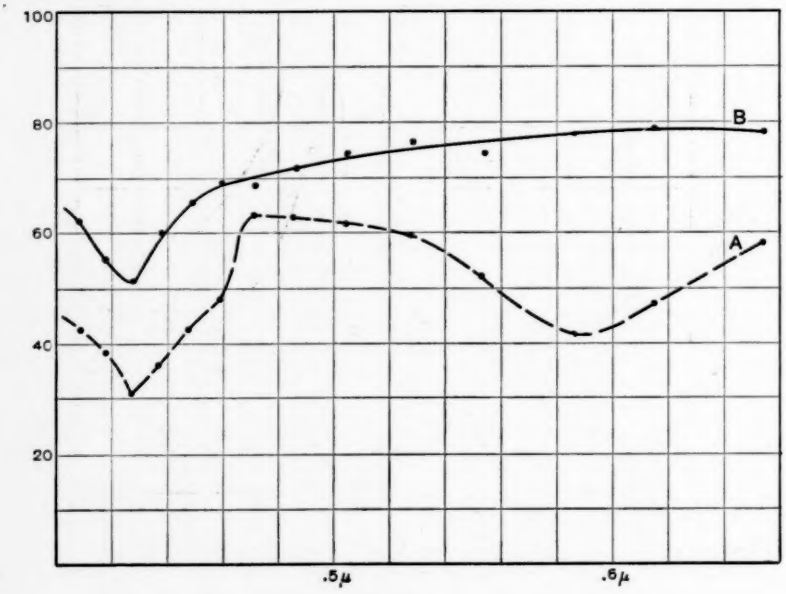


Fig. 18.

Transmission spectra of green fluorspar (A) and white fluorspar (B).

under consideration. The glass which we have examined appears to belong in the same class with all the other fluorescent substances upon which measurements were made: its fluorescence spectrum consists of a single band, the location of which is independent of the wave-length of the exciting light, and it does not obey Stokes' law.

Fluorite.

From a collection of small crystals of fluorspar from Derbyshire, England, placed at our disposal by Professor Gill of the Department of Mineralogy, two specimens were selected for study. One of these was green by transmitted light, the other colorless. Both showed the well known blue-violet color due to fluorescence. The transmission curves of the spectrum of these crystals are brought together for comparison in Fig. 18. Curve *A* of the green spar (thickness 0.8 cm.) contains a broad, well-marked band in the

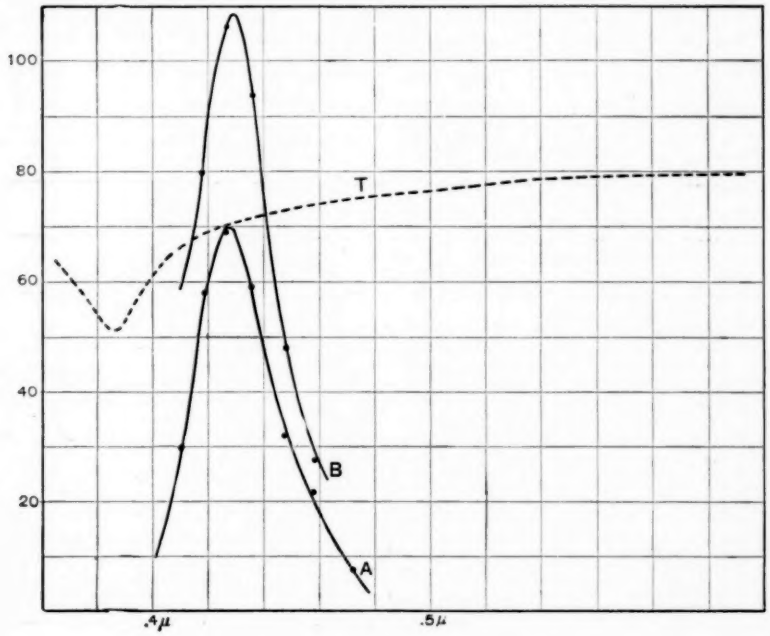


Fig. 19.

Green Fluorite. Curve *A*. Fluorescence spectrum when excited by the carbon arc.
Curve *B*. Fluorescence spectrum when excited by Hg arc.
Curve *T*. Transmission spectrum of a layer 0.8 cm. thick.

yellow and a second rather narrow band, to which the fluorescence is due. The maximum of absorption in the latter band is at .424 μ. Curve *B*, which relates to the white crystal, contains only the second band. This crystal, although thicker (1.72 cm.), is more transparent, the absorption in the middle of the band being less than 50 per cent.

It is interesting to note the presence of easily measurable fluorescence accompanying such feeble absorption. The fluorescence of the green crystal was determined by means of the undispersed light of the ordinary arc (curve *A*, Fig. 19) and of the mercury arc direct (curve *B*). The effective light from the latter source comes chiefly from the lines .407 μ and .365 μ. The fluorescence conforms strictly to that of all substances previously examined by us. The spectrum consists of a single band, the maximum of which at .433 μ is independent of the character of the exciting light.

In the measurement of the fluorescence of the white crystal diffuse daylight was employed, and the observations were made with the spectroscope with a single collimator tube and Vierordt slit, already described. The two sets of readings obtained are plotted in Fig. 20. The curves correspond very closely in character with those

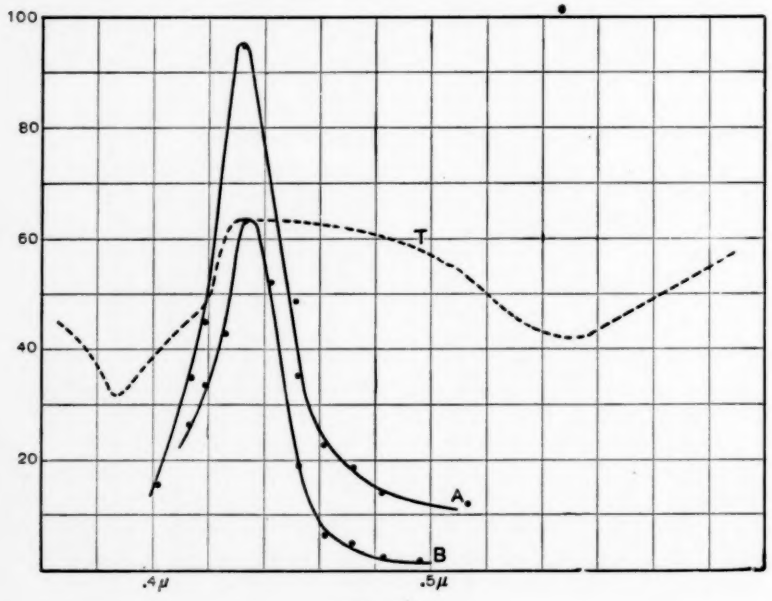


Fig. 20.

White Fluorite. Curve *A*. Fluorescence spectrum when excited by diffuse daylight.
Curve *B*. The same repeated on another day.
Curve *T*. Transmission spectrum of a layer 1.72 cm. thick.

obtained with the green fluorite, although the maximum appears to be shifted very slightly towards the violet. This shift may be due

to a combination of errors of observation and of instrumental errors, the instruments employed being different throughout, or it may result from some slight difference in the character of the absorption band. It will be noticed by reference to Fig. 18 that the infra edge of the absorption band of the green crystal does not rise so sharply as is the case of the white fluorite. The broadening of the band upon this side may result in a slight shifting of the fluorescence. It has already been shown by Stenger[1] and by O. Knoblauch[2] that fluorescent substances, such as eosin and naphthalin-roth, have the position of the fluorescent spectrum shifted by dissolving them in different liquids; and that the shift corresponds with that of the absorption band previously described by Kundt.[3]

Æsculin.

This substance was cited by Lommel[4] as typical of his second class, the characteristics of which are a fluorescence spectrum independent of the wave-length of the exciting source and an absorption band beginning at that point in the spectrum at which the first trace of fluorescence shows itself and extending towards the violet, so that there is no overlapping of the band of the exciting light with the fluorescence spectrum.

Our measurements of the fluorescence of æsculin were made upon a solution consisting of water in which freshly broken twigs of the horse-chestnut tree had been immersed. When freshly prepared this shows the well-known fluorescence characteristic of æsculin, but the solution loses its activity upon standing. We were unable to procure pure æsculin, but the results so far as the form and composition of the fluorescence curve is concerned would probably be the same had measurements been made upon the solution of the chemically prepared substance. The fluorescence curve, Fig. 21, is of the usual form and its position with reference to the transmission curve T is similar to that of the substances previously examined. On the infra side, as has been pointed out by Lommel, it is possible to trace the fluorescence throughout the entire spectrum; but this, as in the

[1] Stenger, Wied. Ann., 28, p. 201.
[2] O. Knoblauch, Wied. Ann., 54, p. 193.
[3] Kundt, Wied. Ann., 4, p. 34, 1878.
[4] Lommel, Poggendorff's Annalen, 143, p. 38.

instances already considered, is due to the greater luminosity as we move toward the middle of the spectrum rather than to any unusual maintenance of the intensity of the fluorescence in that direction. The band falls off quite sharply on that side, differing not at all in this respect from the bands of other substances such as quinine sulphate and fluorite. The measurement of the transmission showed a very dilute solution, in which the maximum of absorption is scarcely more marked than in the case of the bands of the specimens of fluorite already described.

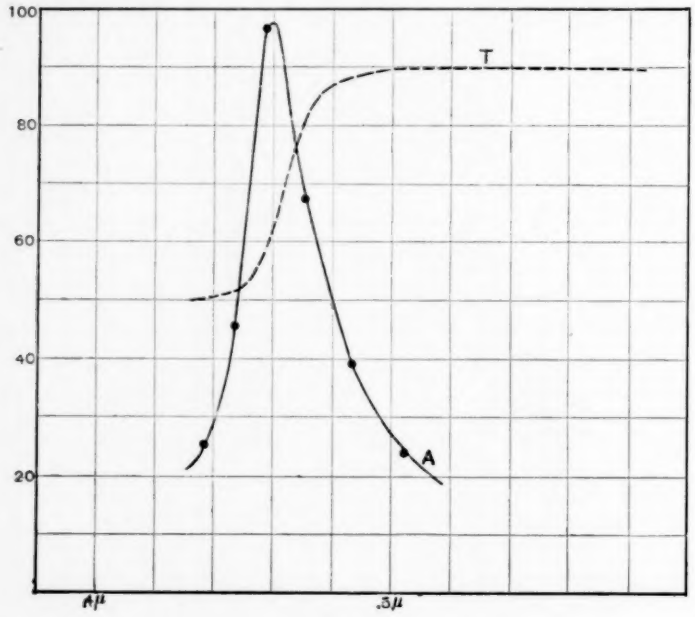


Fig. 21.

Æsculin (from horse chestnut). Curve *A*. Fluorescence spectrum when excited by arc light.

Curve *T*. Transmission spectrum of a layer 8 cm. thick.

From the location of the absorption band with reference to the maximum of fluorescence it would be safe to predict for this substance, on the basis of previous experience, a wide divergence from the law of Stokes. Determination of the limiting value of the exciting light is somewhat difficult to make. It was found, using the spectrum of the arc lamp as a source, that the fluorescence due to light of wave-length .45μ could still be discerned.

It is not possible, with the spectrophotometer, to make a complete exploration of the absorption band of æsculin, since the band extends into the ultra-violet. Photographs of the absorption spectrum of this solution, made by Miss Eleanor Burns at our suggestion show this band to be comparatively narrow, its ultra-edge lying at about .34 μ, beyond which there is no absorption capable of detection by photographic means.

There is nothing in these measurements which would lead one to place æsculin in a class different from that of the foregoing substances. It is distinguished, as regards the character of its fluorescence spectrum, from quinine sulphate and fluorite, the other two substances on our list the fluorescence of which lies in the blue, only in that the maximum lies at a somewhat greater wave-length. The curve *A*, Fig. 21, was obtained by the use of the direct light of the arc, undispersed. Since the curve corresponded in every form to the general type it did not seem necessary to repeat the observations with exciting light of other composition.

Summary.

From the measurements described in this and in our previous paper the following conclusions may be drawn:

1. Eosin, naphthalin-roth, fluorescein, rhodamin, resorcin blau, quinine sulphate, chlorophyll, canary glass, green fluorspar, white fluorspar, and æsculin all exhibit fluorescence of the same type.

2. The fluorescence spectrum in every case consists of a single band situated near the infra edge of the absorption band with which fluorescence is associated.

3. The position of the maximum of the fluorescence band is in all cases independent of the wave-length or composition of the exciting light.

4. The distribution of intensities in the fluorescence spectrum is independent of the wave-length of the exciting light.

5. Fluorescence occuring at the red end of the spectrum is traceable to a greater distance towards the violet, and fluorescence at the violet to a greater distance towards the red, than is the case with fluorescence bands in the middle of the spectrum because of the increase of luminosity in those directions.

6. Stokes' law holds for none of the numerous fluorescent substances thus far examined by us.

7. Fluorescent substances having absorption bands of shorter wave-length than that with which the fluorescence is associated are capable of excitation by the absorbed light in each band, whatever its wave-length.

8. Fluorescent substances may have absorption bands of greater wave-length than that with which fluorescence is associated, as in the cases of green fluorspar and chlorophyll. The light absorbed in these bands does not however produce fluorescence.

9. Where more than one fluorescence band exists, as in the case of chlorophyll, it is probable that each band is due to a distinct fluorescent material contained in the solution. No case is known of double or multiple fluorescence where only one substance capable of fluorescence is present.

We propose in a forthcoming paper to consider the influence of fluorescence upon the absorption and electrical conductivity of fluorescent solutions.

THE VISCOSITY COEFFICIENT OF AIR, WITH AN INQUIRY INTO THE EFFECT OF RÖNTGEN RAYS THEREON. II.

By F. G. Reynolds.

Description of Apparatus.

A VERTICAL glass tube 92.71 cm. long and 6.85 cm. in diameter has its lower end fitted air-tight into a brass collar 7 cm. high which screws into a brass circular bed-plate, 28 cm. in diameter. The lower surface of the plate is ground and polished so that the ground edge of a bell jar when placed against it may form an air-tight connection. The upper end of the glass tube is capped with a brass cylinder in the form of an inverted cup whose upper surface is 3.49 cm. thick and is pierced by a conical shaped opening into which fits the cone of a torsion head, which being carefully ground is capable of easy motion but at the same time is air-tight. The brass collar at the base is fitted with a plane glass window which is adjusted air-tight over a part of the glass tube which has been cut away. In this way the observer may see clearly within that part of the cylinder, since the rays of light are not interfered with by the cylindrical surface of the tube. The bed-plate rests upon a tripod fitted with adjusting screws in its legs so that the glass cylinder may be made vertical. By an arrangement of clamps acting as a wedge, a bell-jar may be attached to the tripod and held tightly against the under surface of the bed-plate.

In the first and second sets of experiments a hollow brass spherical shell was used and careful measurements of its diameter were made for the purpose of determining any variations from a truly spherical form with the result that the diameter used as an axis was found to be very slightly smaller than the diameters perpendicular to it but the difference was so small as to cause no appreciable error in considering the surface spherical. The dimensions were therefore taken as follows: External diameter 12.68 cm. Mass 235.7

grammes and a moment of inertia (calculated) 6316.06. This sphere hung within the bell jar and was attached to the suspending wire by means of a brass rod 28.8 cm. long whose lower end screwed into the sphere and whose upper end was fitted with a cross pin in the shape of a T which fitted into a hook-shaped saddle attached to the wire. The wire was of German silver .0254 cm. in diameter and 79.3 cm. long and was used throughout the entire set of experiments. A small plane mirror was attached to the brass connecting rod, and this was capable of a vertical adjustment so that the mirror could be brought directly opposite the opening in the base of the apparatus. The whole suspended apparatus was thus protected from currents of air, and a very small turn to the torsion head would suffice to set the system into motion, which could be observed through the agency of the mirror. The readings were made by means of a tangent scale and telescope directly in front of the opening opposite the mirror and from 95 cm. to 100 cm. distant therefrom. The temperature of the gas was observed from a thermometer placed within the bell jar and easily read from without. The length of time taken for a swing from one position of rest to the next was obtained by means of a break-second chronometer with an electrical attachment to a recording apparatus from which one one-hundredth second could be estimated. The barometer from which the readings were taken hung near the apparatus.

A preliminary set of experiments was made and the results were calculated for the purpose of determining:

1. The best working limits of the apparatus as used.
2. Whether either the logarithmic decrement or the period of one swing depends upon the amplitude of the same.
3. Whether within the range of future experiments there is any change corresponding to the varying barometric pressure.
4. Any peculiarities liable to occur and therefore to be avoided.

PRELIMINARY SET.

The method of proceeding in this instance was as follows: The sphere was first attached to the brass rod and the latter was then placed with its end in the saddle; the beli jar was then brought

up and with as little jar as possible was clamped into position. Then by means of the torsion head, which was moved first in one direction and then in the reverse, an oscillating movement would be given to the sphere. In many cases a slight pendulum motion would also be given, but with a little practice it was found that this could be entirely stopped by a slight pressure of the hand on the outside of the apparatus. The oscillations were allowed to continue sometimes at the start for an hour, whereby over two hundred vibrations would have occurred, the object of this being to accustom the suspending wire to its load and to the torsional vibrations, so that when the readings proper were taken the damping effect of the internal friction of the wire itself would be reduced to as small and as constant a quantity as possible. The necessity of this precaution was shown by the work of Tomlinson [1] where he found that rest and change of temperature as well as any sudden shock would temporarily raise the internal friction of the wire. After this the sphere would be given a fresh swing and when the amplitude of the swing was that desired, the temperature, barometric pressure and time of start would be noted as well as the starting points on the scale. The readings on the scale were always taken in groups of ten successive swings and at the end of every two or three groups a pressure on the electrical key would record the time. This would continue till two hundred readings had been taken. The method of getting from this the logarithmic decrement is as follows: Suppose a_1, a_2, a_3, a_4, a_5, a_6 and b_1, b_2, b_3, b_4, b_5 are eleven consecutive readings from the left and right of the scale. The ten corresponding arcs from rest to rest are therefore $a_1 + b_1$, $b_1 + a_2$, $a_2 + b_2$, $b_2 + a_3$, $a_3 + b_3$, $b_3 + a_4$, $a_4 + b_4$, $b_4 + a_5$, $a_5 + b_5$, $b_5 + a_6$. The mean of the first and last, second and ninth, third and eighth, etc., would then be taken and if these did not vary much, as was generally the case, the mean of these five would be taken and the logarithm of the corresponding number of seconds noted. This would also be done with the second and succeeding sets of ten readings and the mean of the ten differences between the first and eleventh, second and twelfth, etc., logarithms would when divided by 100 be taken as the logarithmic decrement. These differences would vary slightly

[1] The Influence of Stress and Strain on the Physical Properties of Matter. Phil. Trans., 1886, (2), CLXXVII, p. 801.

but no particular law of variation was noticeable, the variation being sometimes in one direction and sometimes in the other. The accompanying set shows more particularly the method:

s	A	$\text{Log}_{10} A$	$n\lambda$
110.33	22.666	4.35537	
103.65	21.303	4.32844	
97.40	20.027	4.30161	
91.60	18.841	4.27510	
86.19	17.693	4.24780	
81.12	16.695	4.22258	
76.33	15.714	4.19628	
71.85	14.795	4.17011	
67.62	13.926	4.14382	
63.73	13.127	4.11816	
59.96	12.353	4.09177	.26360
56.41	11.623	4.06531	.26312
53.06	10.935	4.03881	.26279
50.05	10.314	4.01342	.26167
47.06	9.700	3.98677	.26103
44.28	9.127	3.96032	.26225
41.75	8.607	3.93485	.26143
39.12	8.065	3.90660	.26351
36.81	7.589	3.88018	.26364
34.67	7.148	3.85418	.26398

in which s represents the respective means of ten consecutive amplitudes as noted on the scale.

A the amplitudes reduced to seconds.

$n\lambda$ a multiple of the logarithmic decrement found by subtracting 11 from 1, 12 from 2, etc.

The mean of the ten differences $n\lambda$ gives .26270 and therefore the average logarithmic decrement for one swing is taken as .002627. The results of such observations taken at different times under varied conditions of barometric pressure and temperature are shown by the table:

Temp.	Barom.	Period.	Amplitude.	Log. Dec.
12.65	30.21	15.98	121.1- 36.9	.0025749
15.25	30.2	15.91	129.5-199.5	.0026061
16.40	29.95	16.	113.7- 33.7	.0026270
16.67	30.15	15.97	168.7- 50.2	.0026283
17.85	30.08	15.98	164.4- 84.2	.0026385
18.15	30.06	15.99	74.1- 38.1	.0026417
18.22	29.81	15.97	200.5-199.5	.0026419
18.30	3.018	15.94	205.1- 60	.0026543

From which it appears:

1. The small difference of barometric pressure has no effect on the logarithmic decrement.

2. The period of oscillation is unaffected by the amplitude of swing or by the temperature.

3. The logarithmic decrement is unaffected by the amplitude of swing.

4. The temperature is the only element which affects the logarithmic decrement. This was further emphasized in two cases where during the observation the temperature changed gradually to the extent of one degree. In one case where the temperature increased, the value of the logarithmic decrement increased steadily instead of varying in one way and the other around the mean value; and in the other case where the temperature gradually fell, there was a steady falling off in the value of the logarithmic decrement.

This sensitiveness to the changes in temperature rendered it advisable in the future observations to confine them to a shorter period of time so that there would be less liability that a change in temperature would occur, and therefore in the following sets the observations were confined to 100 complete vibrations.

Second Set.

With the swinging apparatus as described it was of course impossible to know how large a part of the logarithmic decrement was due to the internal friction of the wire itself and to the action of the air on the mirror. A change therefore was necessary so that this effect could either be eliminated or accounted for. This was accomplished by an addition to the apparatus as before described. A hollow brass tube 14.818 cm. long was pierced by a hole in the plane of its mid-section so as to permit the hanging brass rod to pass through it and to which it was fastened so as to hang 8.6 cm. from the lower end. Great care was necessary in the arrangement of this so that when finished it should hang in a perfectly horizontal position and at right angles to the suspending rod in order not to deflect the mirror. Two solid brass cylindrical weights were now constructed which fitted snugly into the ends of the hollow cylinder and each weight was carefully cut down till it was half the weight of the spherical shell (*i. e.*, 177.85) when the length of each was found

to be 4.842 cm. The moment of inertia of the spherical shell had been calculated to be 6316.06 and it was desired to place each cylinder at such a distance from the axis as to have its moment of inertia equal to 3158.03. The moment of inertia of each around an axis through its center of inertia is 229.93 and therefore 2928.09 is the moment about the original axis of the whole mass considered as placed at the center of inertia. If the distance of the center of inertia from the axis be denoted by x, then $Mx^2 = 2928.09$ from which $x = 4.988$ cm. and since it was also necessary to have the ends of the weights flush with the ends of the enveloping cylinder this determined the proper length of the cylinder 14.818 cm. The aim in this was to reproduce the weight and moment of inertia of the spherical shell in the weight and moment of inertia of the two cylindrical weights.

The method of procedure in this set was as follows:

The cylinders would be removed and the sphere attached to the brass rod and the apparatus then left for several hours, usually over night. At the end of this time, by means of the torsion head the sphere would be oscillated for some time to accustom the wire to the oscillations, and then the vibrations would be started again for the readings, care always being taken to avoid any pendulum motion. In this case 100 complete swings from rest to rest were taken and the time thermometer and barometer noted as before. The sphere would then be detached, care being taken not to jar the wire and the cylinders would then be inserted into place, the preparatory oscillations given and then 100 more readings from the scale with temperature and pressure would be noted. The two swinging systems being the same in every respect save that of the extra surface exposed by the spherical shell, the difference between the decrements when the sphere was swinging and when the counter weights were inserted was that due to the action of the spherical surface alone. The method was varied by taking alternately the sphere readings first and then the readings with the weights first, and the whole extended over a range of eight degrees in temperature during a series of twenty-seven observations. A slight discrepancy in the period of swing was noticed when the sphere was attached and when the cylinders were in place which led to a further investigation to

reconcile the results. The cylinders were removed and circular paper caps were attached to the horizontal hollow cylinder and the time and decrement noted, and compared with the time and decrement when the caps were removed exposing the interior of the cylinder. With the use of the caps the times were found to agree and a slight correction was found necessary to the logarithmic decrement of the sphere as found originally. The corrected results are inserted in the following table:

Time.	Temp.	$\lambda_1-\lambda_2$	Time.	Temp.	$\lambda_1-\lambda_2$
18.965	16.58	.002672	18.97	21	.002819
18.99	16.91	.002679	18.972	21.78	.002851
19.02	17.56	.002691	18.977	22.36	.002873
18.98	18.27	.002717	18.99	23.29	.002904
19.005	19.63	.002760	19	24.61	.002924
18.955	20.72	.002808			

Kirchoff in his "Mechanik"[1] derives a formula involving the coefficient of viscosity, the logarithmic decrement, the time of swing and certain other known elements as follows:

$$\lambda = \frac{2\pi R^4 \sqrt{n\mu}}{3K} \sqrt{2\pi T_0}.$$

In which n = coefficient of viscosity.

μ = density of the medium.

R = radius of the swinging sphere.

λ = the logarithmic decrement.

T = the swinging time in the fluid.

T_0 = the swinging time free from influence of friction.

K = moment of inertia of the system, which in the case of a spherical shell = $\frac{2}{3} Ma^2$.

The relation between the observed T and T_0 is given by:

$$T = T_0\left(1 + \epsilon\sqrt{\frac{2T_0}{\pi}}\right) = T_0\left(1 + \frac{\lambda}{\sqrt{\pi}}\right)$$

Using for the density of the air the value .001293 in the above formula the value of the coefficient of viscosity at the temperature 20.72 was calculated to be .00018697.

[1] Vierte Aufl. 26 Vorlesung, p. 383.

THIRD SERIES.

The object of this series was to see if, with an entirely different swinging system, results could be obtained which would approximate closely the results obtained with the spherical shell. Such agreement if obtained would justify the mathematical theories giving rise to the formulæ used.

For this purpose two hollow brass cylinders were procured and after careful tests were found to depart but the slightest from exact uniformity of measurement. The dimensions were as follows:

Cylinder.	Length.	Weight.	Inside Diameter.	Outside Diameter.
A	30.4 cm.	327.8 gr.	5.00	5.08
B	30.4	316.3	4.70	4.78

A thin circular brass cap was soldered to one end of the smaller cylinder in the center of which was fastened a perpendicular brass rod 16 cm. long so that it coincided exactly with the axis of the cylinder. In a manner similar to the one used with the sphere, this rod was fitted at the top extremity with a cross-pin to rest in the hanging hook on the wire. The wire was the same one as used before, its length being this time 80.1 cm. By means of two small felt collars, one on the lower end of the smaller cylinder and the other on the upper end of the larger one, the larger when placed over the smaller was held snugly in place and the whole, when placed on the suspending wire, hung in a perpendicular position with the axis of the two cylinders coinciding with the wire. This telescopic arrangement of the cylinders permitted the outer one to be drawn out over the inner one or pushed back so as to cover it and in this way was it possible to eliminate the effect of the friction of the wire and the action of the air on the mirror. Two marks 25.4 cm. apart were made on the inner cylinder and the extension was limited to this amount. In the same manner as before the readings were made from the scale and the temperature, time, and pressure were noted. The observations were always made in pairs; one set with the cylinders collapsed and the other with the cylinders extended and alternately, one set and then the other being taken first. The results of 34 sets with temperature varying about six

degrees were of a very satisfactory character. The time of swing averaged 13.09 seconds, any one differing from this by less than .05 seconds.

Temp.	Cylinders Extended.	Temp.	Cylinders Collapsed.
21.4	.001504	21.25	.000953
22.11	.001507	22.73	.000954
22.75	.001509	23.35	.000956
23.6	.001518	24.3	.000960
24.35	.001522	25.52	.000961
25.21	.001526	25.61	.000962
25.95	.001529	25.7	.000964
26.38	.001531	26.73	.000966
27.1	.001533	27.4	.000969

The differences between the two corresponding logarithmic decrements vary from .000551 to .000564 and these differences were taken for the logarithmic decrement corresponding to a cylinder of the internal and external diameters of the smaller cylinder and 25.4 cm. in length.

From the mathematical deductions of Stokes the logarithmic decrement due to the action on the walls of the cylinder will be given by:

$$\lambda = \frac{M\mu T}{I\rho} \log_{10} e(\sqrt{2} \times f + \sqrt{2} \times 0.375 f^{-1} - \sqrt{2} \times 0.4922 f^{-3} + \text{etc.})$$

where

$$f = \sqrt{\frac{\pi\rho}{\mu T}} \times a.$$

In which λ = the logarithmic decrement.

M = mass of air confined in a cylinder of same length and mean radius of the one considered.

μ = the coefficient of viscosity.

T = the observed time.

I = the moment of inertia of the cylinder considered.

ρ = the density of the air considered as about half saturated with moisture.

a = the mean radius of cylinder.

In applying the formula a first approximation was made for the value of μ and this used in a second approximation. A third was

found unnecessary and the value of μ resulting from an observed time 13.09 seconds, a logarithmic decrement .000551 and at a temperature 21.33 was calculated to be .00018711.

This value agrees very closely with the value found by the preceding method, and both agree well with the later results of other investigators, as may be seen by the table.

FOURTH SERIES.

Attention has been called by Thomson [1] to the facility with which a gas can be changed from a conductor to a non-conductor by the application and removal of Röntgen rays; and in particular he caused the gas so exposed to be swept past a wire charged with electricity and in this way part of the charge would be carried to an electrometer. When the ray was not acting on the gas no charge was carried over by the gas. The gas it was found loses this conductivity when a current of electricity passes through it and also when forced through a plug of glass wool, which latter fact would indicate that the structure in virtue of which the gas conducts is of a coarse character since it does not survive the passage through the fine pores of the glass wool. The study of any other property of a gas when in the state into which it is thrown by the Röntgen ray might therefore lead to further interesting and valuable results. The object of this phase of the investigation is to ascertain if there is any difference in the coefficient of viscosity of air when it is affected by the influence of the Röntgen rays.

In this set the brass spherical shell used before was hung in position and the bulb from an X-ray apparatus was brought within 15 cm. of the surface of the sphere. It was found necessary to have the coil in an adjoining room in order to keep the floor and air free from the vibrations of the apparatus. Furthermore in order to shield the air surrounding the sphere from the electrostatic influences of the bulb, the latter was surrounded by a metal gauze screen which was connected to the earth. The observations were taken in pairs, with the current alternately on and off, and attention was first directed to the period of swing. The following table, where the average time of ten consecutive swings is given, at different temperatures and barometric pressures, gives no evidence of any uniform law of change:

[1] Discharge of Electricity through Gases, Phil. Mag., 1896 (5), 208, p. 392.

Temp.	Bar.	Without Rays.	With Rays.	Amplitude.
15	29.6	15.985	16.	80 –70
"	"	15.97	16.	19 –13.5
"	"	15.95	16.94	
16.6	29.77	15.98	15.98	35 –30
17.75	"	15.94	15.96	70 –64
17.75	"	15.965	15.94	65 –56
		15.97	15.96	84.7–71.5

At a later time further sets were taken with a slight change in the swinging apparatus and at higher temperatures and the logarithmic decrement as well as the time were noted for comparison. The method of procedure consisted in taking the readings of thirty complete oscillations with the current off, then thirty more with the current on, and a final thirty with the current off again. The interval between each two sets of thirty being the same, usually one complete oscillation. The average of the first and third sets was taken and compared with the second set with the following results :

Time Off.	Time On.	Current Off.	Current On.	Amplitude.
15.68	15.7	.0025498	.0025428	112 - 94.9
15.7	15.73	.0025681	.0025647	56 - 47.6
15.7	15.7	.0026147	.0026042	38.4– 32.4
		.0026893	.0026223	84.7– 71.5
15.7	15.73	.0025472	.0025471	120.6–102.3
		.0026653	.0026273	151.3–126
15.7	15.7	.0025697	.0025648	100.8– 85.4
15.7	15.7	.0025791	.0025729	70.6– 59.8

In this set the periods agree closely. It might be noted that the variation favors usually a slight increase in the period of swing when the air is affected by the Röntgen ray, but the difference is so small that this might easily be caused by errors in observation. In the case of the logarithmic decrement the difference is also very slight but points to a decrease when the gas is under the influence of the Röntgen ray. The effect furthermore seems to be an increasing one within the limits of the time given, since in striking the average decrement for the gas when under the influence of the rays, the final terms were less and the first terms greater than this average as given. During each set the current was kept practically uniform, but it was varied in the different sets wherein the more pronounced effect accompanied the stronger current.

COLLEGE OF THE CITY OF NEW YORK.

THE APPLICATION OF ALLOTROPIC SILVER FOR THE PREPARATION OF CONDUCTING FIBERS.

BY N. A. DUBOIS.

A NUMBER of articles discussing allotropic modifications of silver have appeared in the various journals since 1889. These articles treat rather of the methods of preparation and physical condition of the different allotropic modifications, than of any application of them. A complete list of references is given by Barus and Schneider.[1]

Three forms of allotropic silver are described, all of which have certain properties common to themselves and which distinguish them from ordinary silver.

When a suspension or emulsion of any of these forms of allotropic silver is spread over paper and dried, the particles are left in optical contact and thus form an apparently continuous film.

Treatment with halogens produces brilliant interference color effects. All the forms are very readily changed to an impalpable powder. Treatment with acids instantly changes all forms to ordinary silver, with apparently no chemical action. No gas is evolved.

It is the purpose of this article to give a simple and efficient means for the preparation of conducting fibers; whether they be used for suspension, as in the quadrant electrometer, or otherwise; and whether the fiber material be quartz or any other suitable substance.

The allotropic silver used was prepared according to the process described by Carey Lea.[2]

A mixture of 200 c.c. of a 30 per cent. solution of ferrous sulphate and 280 c.c. of a 40 per cent. solution of sodium citrate was treated with a 10 per cent. solution of sodium hydroxide, just till no permanent precipitate formed. This was then mixed with 200 c.c. of a 10 per cent. silver nitrate solution stirred thoroughly, allowed to

[1] Wied. Ann., XLVIII., p. 327, 1893.
[2] Am. Jour. Sci., XXXVII., p. 476, 1889.

settle and the liquid decanted. The precipitated allotropic silver was treated with about 200 c.c. of distilled water, which dissolved a part of it, and was again precipitated by treatment with a saturated solution of ammonium nitrate. This process was repeated three times, and the final precipitate filtered with suction and washed with 95 per cent. alcohol. The product was transferred, in the form of a brown mud, to a bottle and kept covered with alcohol.

The allotropic silver was used for the experiments as an emulsion in alcohol, alcohol being used rather than water as it dries more quickly and thus the dry film of allotropic silver can be obtained in a very few minutes after spreading the emulsion.

This emulsion spread on any surface and dried gave a copper-colored film. When dried on a glass plate and viewed through the glass, it gave a good mirror, but of a dark color.

When these films were treated with gaseous hydrochloric acid they were immediately changed to ordinary silver and presented a dull silvery appearance. The films are changed to a bright silver surface by slight friction. It was the action of the gaseous hydrochloric acid, which suggested the investigation.

Glass plates were painted with the emulsion and dried. The conductivity of the films in this condition was found to be very poor. It was tested by placing the terminals of an ordinary dry battery upon the films with an ammeter in circuit. The electromotive force of the battery was about two volts and the terminals were placed eight or ten centimeters apart.

The films were then treated with gaseous hydrochloric acid by blowing through an arrangement like a reversed wash-bottle, the bottle containing a little strong hydrochloric acid. By this means a stream of gaseous hydrochloric acid was very readily directed upon the allotropic silver films, thus changing them to sheets of ordinary silver. These films were then tried with a battery as before and found to be excellent conductors.

The use of the silver was then tried on the quartz film of a quadrant electrometer as follows: The quartz fiber, suspending the aluminium needle between the hollow quadrants, was hung from a hook which was thoroughly insulated with hard rubber. The

whole was enclosed in a copper case to prevent disturbance by air currents and a beam of light reflected through a glass window in the copper case, from a mirror fixed on the needle, served as a pointer on a transparent scale arranged at the proper distance.

The instrument having been adjusted, experiments were tried to see how quickly the needle responded on being charged. It was found to respond instantaneously.

Various tests on the electrometer with the fiber prepared as above stated were perfectly satisfactory.

CONCLUSIONS.

The dried films of allotropic silver, although poor conductors, become very good conductors on treatment with gaseous hydrochloric acid.

The emulsion can be used admirably for the preparation of conducting fibers; and can be applied to the most delicate apparatus in a very few minutes, without danger of injury.

The above work was done in the physics laboratory of Brown University. In closing, the writer wishes to express his thanks to Professor Carl Barus, for his valuable instruction and friendly aid.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

APPARATUS FOR PLATINUM RESISTANCE THERMOMETRY.[1]

BY C. W. WAIDNER AND H. C. DICKINSON.

THIS paper contained:

1. An outline of the development of resistance thermometry.

2. A description of some special forms of resistance thermometers, which are taken to establish the scale of temperature used by the National Bureau of Standards in the interval from — 200° C., or lower, to upwards of 600° C.

3. The description of a special form of resistance bridge that has been designed for use with resistance thermometers of the 'compensated lead' type, which combines high accuracy with rapidity in working. This bridge may be briefly described as a mercury contact bridge, with a series of coils embodying the essential features of standard resistance coils, ranging from 0.01 ohm to 50 ohms; the finer settings being made on three 10-step shunt dials, which take the place of a bridge wire and which read in steps of 0.001, 0.0001, and 0.00001 ohm respectively. The adjustment of these coils in the shunt dials need only be approximate, without introducing an appreciable error. This bridge also contains all the necessary reversing battery and galvanometer keys and an Ayrton-Mather shunt, and four sets of ratio coils that can be conveniently reversed for eliminating inequalities in the ratio arms.

BUREAU OF STANDARDS,
WASHINGTON, D. C.

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 23, 1904.

THE INTERCOMPARISON OF PRIMARY STANDARD MERCURIAL THERMOMETERS.[1]

BY C. W. WAIDNER AND H. C. DICKINSON.

ONE of the first problems to present itself in connection with the work of the Thermometry section of the Bureau of Standards was that of a temperature scale in the interval 0° to 100° C. together with a suitable means for accurate and convenient intercomparison of primary standard and other accurate mercury thermometers in this range.

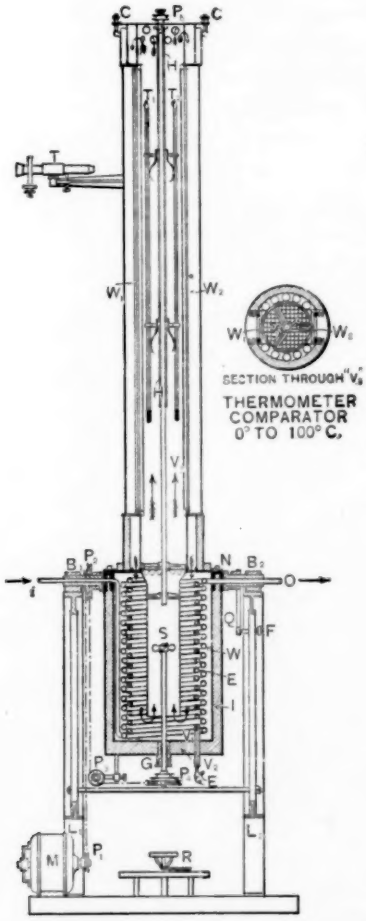
The scale of temperature in almost world wide use is the International Hydrogen Scale established by the experiments of Chappuis. Hydrogen was chosen because of its near approach to a perfect gas throughout a great range of temperature and its consequent close agreement with the absolute thermodynamic scale. This scale is made available by the work of the International Bureau of Weights and Measures who have made a complete study of the hydrogen thermometer and have compared with it various mercury in glass thermometers constructed of different kinds of glass. It is thus possible to reduce the indications of a mercury thermometer to the hydrogen scale.

The advantage resulting from the adoption of a standard temperature scale cannot be too strongly emphasized. Before this work was carried out by the International Bureau each experimenter was obliged to set up his own air thermometer and establish his own temperature scale. This often required far more time than the experiment itself, *e. g.*, in the classical determinations of the mechanical equivalent of heat by Rowland. This had the further disadvantage that the results of different experimenters could not be compared to the greatest advantage. As an illustration of the advantage of the world wide use of a single scale we need only refer to the explanation of the discrepancy that had been found in the mechanical equivalent of heat when measured by mechanical and electrical methods. When the apparently discordant results were reduced to the same temperature scale they were found to be in most satisfactory agreement in the variation of the specific heat of water, and further strongly indicated an error in the International electrical units, which was almost simultaneously confirmed by the redeterminations of the E.M.F. of the Clark cell by Kahle and by Patterson and Guthe.

The Bureau of Standards possesses a number of primary standards made from French hard glass by Baudin and by Tonnelot. These thermometers are of the very finest construction, graduated in tenths of a degree with lines (on those by Baudin) less than 20 microns in width. Each

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 23, 1904.

thermometer has been calibrated at the International Bureau and some of them have been compared directly with their standards. The temperature scale of the Bureau of Standards in the interval 0° to 100° C. is established by the mean of a large number of intercomparisons of these primary mercurial standards in a specially constructed comparator which is designed to satisfy the requirements for the very highest accuracy and at the same time permits great rapidity and convenience of manipulation so that it can be used readily for even coarse comparisons of ordinary thermometers.



This comparator (see accompanying cut) is essentially a triple walled water bath which can be used in either horizontal or vertical position, with water coil for rapid heating and cooling, electric coil for heating, and rapid circulation of water produced by an electrically driven pro-

peller. The upper part of the tank is made of three concentric brass tubes and contains within the inner one a holder with places for fourteen thermometers. Between the outer two of these tubes is a packing of hair felt and between the inner two the downward circulation of water which comes upward around the thermometers in the inner space. Plate glass windows (W_1) (W_2) 60 cm. long and about 8 cm. wide are let in on opposite sides for the purpose of reading. These windows being opposite each other afford excellent direct illumination.

The reading is done by means of the micrometer microscope (T) sliding on a vertical support beside the window. The holder (H) may be conveniently rotated to bring the thermometers successively into the field of the microscope, by means of a belt running from the pulley (P_5) in the water tight cover, over idlers to a wheel (not shown) at a convenient height on the back of the tank. The lower portion of the comparator consists of an inner brass chamber covered with a heavy layer of felt and a removable outer brass casing. In this inner chamber are contained all the means for securing temperature regulation and circulation of water. First there is a coil of three-eighths inch copper tubing (W) making sixteen turns with inlet and outlet (i and o) through the axle on which the comparator is supported. Through this coil either hot or cold water may be circulated at will. For temperatures below that of the room, regulation is secured by using water at 0°C. from an ice tank, but at higher than room temperature hot water is used only for rapid heating, and for exact regulation the electric heating coil (E) furnishes the energy. This electric heating gives better regulation than hot water. The coil (E) is of a type made by the Simplex Electric Heater Company for the general trade and was found to fulfil the requirements of this apparatus very well indeed. It consists of three-eighths brass tube in which are inserted two coils, combinations of which give three rates of heating for any E.M.F. and in conjunction with the rheostat (R) permit regulation from a fraction of a watt to 800 watts.

Stirring is effected by means of a propeller (S) driven by the one-tenth horse power motor (M) which is belted to a wheel on the axle of the comparator, from which another belt runs over idlers to the pulley on the propeller shaft. This shaft passes through the stuffing box (G).

The reason for this arrangement was to permit one of the most convenient features of the comparator, *i. e.*, the adaptation to horizontal as well as vertical comparison. By simply drawing the spring key (F) tipping the comparator to a horizontal position and releasing the key, the comparison of a set of thermometers may be continued in horizontal position without any change whatever in the working of any part of the comparator other than possibly a slight change in speed of circulation due to difference in the fluid friction.

With this apparatus and with reasonable constancy in the temperature of the room any temperature within the range of 10° C. to 90° C., may be quickly attained at a rate of two to four degrees per minute and may be held constant to within the limit of the best eye estimations for many minutes. In fact the rise of temperature may be made slower than is desirable for a good set of observations.

It has seemed in most of our work with practice in estimation that a large number of comparisons by eye estimation are better than a limited number of micrometer measurements. These estimations have been found to differ very seldom by as much as three thousandths of a degree from measurements with a micrometer, and the time required for such an eye observation is only a small fraction of that required for the use of the micrometer. The accompanying table gives the observations and results for a set of five double series of eye estimated readings on four primary standards. There were six thermometers in the tank at the time and the

Intercomparison of Primary Standard Thermometers.

	Baudin 15282	Tonnelot 4334	Tonnelot 4335	Tonnelot 4624
	30.013	30.206	30.000	30.128
	30.014	30.205	30.000	30.127
Corrected T.=	29.987	29.992	29.992	29.986
	30.013	30.207	30.002	30.133
	30.020	30.208	30.004	30.133
Corrected T.=	29.990	29.994	29.995	29.993
	30.023	30.210	30.006	30.140
	30.026	30.213	30.008	30.142
Corrected T.=	29.998	29.997	29.997	30.000
	30.031	30.218	30.008	30.145
	30.030	30.218	30.009	30.150
Corrected T.=	30.005	20.004	30.000	30.006
	30.035	30.222	30.010	30.150
	30.035	30.222	30.012	30.153
Corrected T.=	30.009	30.008	30.003	30.010
Mean =	29.998	29.997	29.997	29.999

Sample Computation Baudin 15282

Observed.	30.013
Calibration.	+.055
Ext. Pressure.	−.007
Int. Pressure	+.042
Fundamental.	+.032
Zero Corr.	−.046
To Hydrogen.	−.102
Temperature.	29.987

interval between successive readings was fifteen seconds by the chronometer. Thus between the two readings of the last thermometer three minutes had elapsed and allowing for time between series the whole set required not less than twenty minutes, probably thirty; thus it will be seen that during this time the rise of temperature was approximately .02

degree. The observations here copied are an entirely fair sample being taken directly from one of the record volumes and in many cases the temperatures have varied much less than in this example.

The final results of the complete series of intercomparisons of the primary standard mercurial thermometers will be given in a subsequent communication.

BUREAU OF STANDARDS,
WASHINGTON, D. C.

ABSOLUTE MEASUREMENT OF CAPACITY.[1]

BY E. B. ROSA AND F. W. GROVER.

MEASUREMENTS of the capacity of air and mica condensers were made by Maxwell's bridge method, using a rotating commutator in the fourth arm of the bridge, for charging and discharging the condenser. This commutator was of new design and was built in the instrument shop of the Bureau of Standards. Its special feature consisted in having the two contact brushes, through which the charge and discharge took place, so arranged as to afford air insulation, when the brushes were not in contact with the metal segments, and so prevent any appreciable leakage across the bridge arm.

The commutator was driven by a large electric motor, which received current from a storage battery, and the speed was maintained constant by means of a carbon rheostat in the armature circuit of the motor. The criterion of uniform speed was the balance of the bridge, which was indicated by zero deflection of the galvanometer. It was found possible to maintain speeds more nearly constant in this manner than when using a stroboscopic method with a tuning fork. The exact average value of the speed was determined by registering every fiftieth revolution of the commutator on a chronograph cylinder by means of an electric contact.

Numerous of determinations of capacity were made; the following determinations illustrate the order of accuracy obtained.

Two determinations of the capacities of each condenser were made, and then they were joined, first in parallel, and secondly in series, and two determinations were made in each combination. The means of the two in each case are as follows:

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 23, 1904.

No. 1	= 0.029292 microfarad
" 2	= 0.029481
Sum	= 0.058773
Measured sum	= 0.058770
Difference	= 0.000003
¼ sum	= 0.014693
Measured in series	= 0.014699
Difference	= 0.000006

Two determinations of the capacity of two mica condensers, separately and then in series and parallel were made, the means being the following :

No. 1	= 0.200882
" 2	= 0.200145
Sum	= 0.401027
Measured sum	= 0.401004
Difference	= 0.000023
¼ sum	= 0.100257
Measured in series	= 0.100215
Difference	= 0.000042

This method is used in determining the capacities of condensers submitted to the Bureau for test.

Absolute Measurement of Inductance.[1]

By E. B. Rosa and F. W. Grover.

THE method used was originally proposed by Joubert, but, so far as the authors know, it has never before been employed for an accurate determination of inductance.

The method consists in joining a non-inductive resistance in series with the inductive resistance to be measured, and passing an alternating current through them. An electrometer is then connected so that it may measure successively the difference of potential at the terminals of the inductive resistance and the non-inductive resistance, and the latter is varied until the two readings of the electrometer are equal. The current and voltage being the same for each, it follows that the impedance of the inductive resistance is equal to the resistance of the non-inductive resistance. The inductance of the former can then be calculated when the

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 23, 1904.

frequency of the current and the resistance of the inductive coil are known.

The frequency is determined in the same manner as when measuring capacity absolutely, namely, by recording every fiftieth revolution of the generator on a chronograph. To keep the speed constant, a condenser is joined up to a Wheatstone bridge, and the galvanometer deflection is kept zero by hand regulation of the motor current. In other words, the condenser experiment is here used as an auxiliary to the inductance measurement.

If the wave form is not a true sine curve (as it never is), it is necessary to apply a correction to the result, computed on the assumption of a sine wave, and the value of this correction depends on what harmonics are present, and on their relative magnitudes. If the harmonics are very small, the correction is also small. The authors used a generator, constructed especially for the Bureau of Standards, so as to give as nearly a sine curve as possible and the only harmonic present to an appreciable extent was the third. The analysis showed this to be 1.6 per cent. of the fundamental, no other being more than one or two tenths of one per cent. The correction calculated for this harmonic amounted to about twelve parts in ten thousand.

The work is to be repeated and an effort made to ascertain more exactly the values of the small higher harmonics, if they are present at all.

The following determinations of the inductance of two coils were given by the authors.

$$L = \frac{F}{p}\sqrt{R^2 - r^2}.$$

Coil No. 1.		Coil No. 2.	
R = 962.55	681.85	949.40	672.30
r = 93.5	93.5	93.5	93.5
n = 150.106	105.808	150.104	105.809
F = 0.9988	0.9988	0.9988	0.9988
L = 1.01455	1.01472	1.00055	1.00023
Mean = 1.0146		Mean = 1.0004	
Ratio = 1.0142			

R = non-inductive resistance to balance.
r = resistance of the coil.
n = frequency of the alternating current.
F = correction factor for presence of harmonics.
L = inductance in henries.

This ratio was verified by direct comparison of the two coils.

Testing of Mica Condensers.[1]

By E. B. Rosa and F. W. Grover.

IN estimating the value of a condenser, it is necessary to know:

1. Its change of capacity with the time of charge, *i. e.*, its capacity curve.
2. The magnitude of its absorbed charges.
3. Its leakage resistance.
4. Its temperature coefficient.

The author made determinations with about thirty mica and paper condensers, belonging to the Bureau of Standards, and made by some of the best manufacturers of England, France, Germany and America, with a view to ascertaining the performance of good condensers.

I. To study the variation of capacity with the time of charge, for charging periods of one half second and upward a ballistic galvanometer was used. This had a period of 17 seconds for a double vibration and a remarkably steady zero, so that deflections as great as one meter could be read to two or three parts in ten thousand, and the mean of several determinations would give the deflection to about one part in ten thousand. The deflections being very nearly equal, the relative capacities as the time of charge is varied may be obtained directly from the ratio of the deflections.

For shorter charging periods such as occur with alternating currents, comparisons with a standard may be made with an accuracy of one part in ten thousand, using the alternating current bridge method, with an oscillating galvanometer, tuned to the frequency of the current, for a detector.

To combine these two methods so as to obtain a curve showing the change in capacity from a charging period of a few thousandths of a second up to half a minute we used an air condenser. Since the capacity of an air condenser is independent of the charging period within the prescribed limits the condenser first compared with the air condenser by the alternating current bridge and then a ballistic comparison of the two condensers was made, the voltages being chosen so that they gave very nearly equal deflections. The charging voltage was measured and maintained constant by a potentiometer. The air condensers recently constructed in the instrument shop of the Bureau of Standards were employed. Their combined capacity is nearly 0.06 m.f., and their leakage is negligible.

The mica condensers tested showed curves very much alike as will be seen from the following table for seven condensers. The capacities at

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 23, 1904.

the different charging periods are all referred to the capacity at 10 seconds charge as unity.

Time of Charge.	Condenser. 1	2	3	6	7
$\frac{1}{300}$ sec.	0.9914	0.9902	0.9906	———	———
$\frac{1}{2}$ "	0.9964	0.9952	0.9962	0.9952	0.9971
1 "	0.9977	0.9975	0.9977	0.9968	0.9980
2 "	0.9984	0.9985	0.9984	0.9978	0.9989
5 "	0.9996	0.9996	0.9996	0.9994	0.9995
10 "	1.0000	1.0000	1.0000	1.0000	1.0000
20 "	1.0004	1.0005	1.0005	1.0006	1.0005

II. Residual charges were measured by a very sensitive ballistic galvanometer, the following schedule being used: (1) Charge to seconds. (2) Insulate 1 sec. (3) Short-circuit 1 sec. (4) Insulate 30 sec. and then discharge, a moment observing the quantity. This was called the first residual charge. (5) Insulate 30 sec. and then observe the second residual charge and so on. Two values of t were used, $t = 1$ sec. and $t = 10$ sec.

The following table shows the values of the first five residuals for three mica condensers for two different periods:

$t = 1$ sec.			$t = 10$ sec.		
Condenser.					
2	6	7	2	6	7
0.403	0.328	0.237	0.644	0.832	0.511
0.028	0.028	0.020	0.054	0.114	0.059
0.004	0.010	0.012	0.018	0.036	0.024
——	0.008	0.005	0.014	0.021	0.013
——	0.006	——	0.007	0.016	0.009

These residual charges are expressed in per cent. of the original or CV charge.

Some other mica condensers have shown still larger residuals.

III. The leakage resistance was measured by charging the condenser, insulating it and filling it up again through a ballistic galvanometer at stated equal intervals, the process being repeated until the approaching constancy of the deflection showed that the quantity disappearing by absorption was approaching zero. The values below illustrate the order of magnitude found for the best condensers. Much smaller values have been found for some mica condensers.

Capacity.	Leakage Resistance.
0.1 mf.	2,120,000 megohms
0.2 "	1,500,000 "

IV. The authors have not as yet investigated the temperature coefficients of the condensers, but are about to take up the subject at length. Preliminary observations show, however, that the coefficient for mica condensers may be either positive or negative, but is small, not being very different from 0.0001 per degree.

Optical Pyrometers and Some Problems in Optical Pyrometry.[1]

By C. W. Waidner and G. K. Burgess.

THIS paper, which will shortly be published in full, contains a study of the sources of error, attainable accuracy, necessary precautions in the use of, and the calibration and range of certain optical pyrometers: The LeChatelier, Wanner, the Holborn and Kurlbaum, and the Féry. The advantages and limitations of optical methods in pyrometry are discussed and the results of investigations are given with experimental data on the influences that may affect the indications of the various instruments, such as polarized light emitted by incandescent surfaces, diffuse and reflected light from neighboring luminous bodies, and selective radiation from the sources studied including platinum, copper and iron oxides, lime, flames and other incandescents.

Bureau of Standards,
Washington, D. C.

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 23, 1904.

NEW BOOKS.

Baltimore Lectures on Molecular Dynamics and the Wave Theory of Light. By LORD KELVIN. Cambridge University Press; Baltimore, Johns Hopkins Press, 1904. Pp. xxii + 694. Price $4.50 net.

Before attempting a review of this volume it may be well to say a few words concerning its personal history. In October, 1884, Lord Kelvin, on the invitation of President Gilman of the Johns Hopkins University, Baltimore, delivered a course of lectures in the University before an audience of students and teachers who were assembled from all parts of America. As Lord Kelvin says in the preface to the present volume, he chose "as subjects the Wave Theory of Light with the intention of accentuating its failures." There were twenty lectures, the first on October 1, the last on October 17. The permanent audience numbered twenty-one, and by a happy suggestion of Professor George Forbes, these members of the audience were called the "twenty-one coefficients," reference being made, of course, to the twenty-one coefficients required in Green's dynamical treatment of an elastic solid. In giving these lectures Lord Kelvin spoke with perfect freedom, almost extemporaneously, preparation being made to-day for the lecture of to-morrow, so that the listeners had the inestimable benefit of observing how the master mind attacked and developed problems of difficulty. The lectures were reported stenographically by Mr. A. S. Hathaway, who had been a Fellow in Mathematics in the Johns Hopkins University, and this report was published in the fall of 1884, and has served as a basis of this present volume. In preparing these lectures for the Press, Lord Kelvin found so many new problems and new points of interest that he believed it unwise to print the lectures without a thorough revision. This has occupied the past twenty years, and the volume before us contains the substance of fifteen of the original lectures with numerous additions, comments, etc., together with Lord Kelvin's present views concerning the subjects of the last five lectures, and twelve appendixes on allied subjects.

There are several difficulties in reviewing this volume. One of these is owing to the numerous subjects which Lord Kelvin treats, a difficulty which is apparent if one notes the subjects of some of the chapters: ordinary and anomalous dispersion; double refraction; dynamics of an

elastic solid; dynamics of a row of connected particles; fluorescence and phosphorescence; metallic reflection; dynamics of absorption; energy of waves; dynamics of dispersion; mechanical value of sunlight and possible density of the ether; molecular dimensions; the color of the sky; opacity of metals; Freshnel and Green's theories; kinetic theory of gases; clustering of gravitational matter; the equilibrium of several "electrions" in an atom; the viscosity of ice; waves and ripples; the molecular dynamics of a crystal; electric and magnetic screening; electric waves and vibrations in a submarine cable; etc. Another difficulty in attempting a review comes from the fact that within the past ten years physics has developed along lines essentially different from those which are treated in this volume, and therefore one lacks that interest which would have been aroused if it had appeared twenty or even fifteen years ago.

The object of the lectures is to attempt to explain the properties of the ether, both in interstellar space and in matter, the treatment being based definitely on the elastic solid theory. At the close of the course of lectures in October, 1884, there were still many points for which no such explanation had been given, but in the preface to the present volume Lord Kelvin says: "It is in some measure satisfactory to me, and I hope it will be satisfactory to all my Baltimore coefficients still alive in our world of science, when this volume reaches their hands; to find in it dynamical explanations of every one of the difficulties with which we were concerned from the first to the last of our twenty lectures of 1884."

There are many problems in light the solution of which does not require any explicit statement as to the assumptions concerning the nature of the ether and of its connection with matter, but by far the most interesting and important phenomena are those which do involve some conception as to these properties. In all these cases Lord Kelvin assumes that the ether has only those properties which ordinary matter is known to have; and this material conception of the ether forms the basis of the whole volume. (There is no mention made of the theories of Lorentz or of Larmor.) By a series of most ingenious hypotheses Lord Kelvin shows how an elastic solid theory of the ether can be devised, starting from the theory of Green, so as to explain the ordinary phenomena of reflection and refraction. He further expresses in the form of an equation the properties of an atom which will explain dispersion. But it is difficult to imagine chapters to be more difficult to read than these: the subject matter is so condensed and the discussions are so mathematical. If it were not for the frequent brilliant illustrations and analogies one might say that certain chapters could not be read. One notes with regret the absence of reference to many recent investigations which have important bearing on the subjects discussed, and it is difficut to under-

stand why metallic reflection should be treated as independent of anomalous dispersion.

There has rarely, if ever, appeared a book which contains discussions of so many physical problems as this. In fact for many years to come the student of physics will find it to his advantage to refer to these lectures for help in almost any difficulty that may occur to him. He will surely find in it what he needs. It is impossible to express in words the enthusiasm that was felt by Lord Kelvin's audience as they listened to his daily lectures, and it is equally impossible to give any proper idea of the importance of the present volume, in as much as it contains the matured thoughts of the greatest master of physical science now living. One may regret that the line of activity is that chosen, but nothing can detract from the importance of the subject and its treatment.

The volume is a handsome book of 694 large octavo pages and is a credit to its publishers, the Cambridge Press. There is an elaborate table of contents but no index, an inexcusable neglect in any book, but specially in this case.

J. S. AMES.